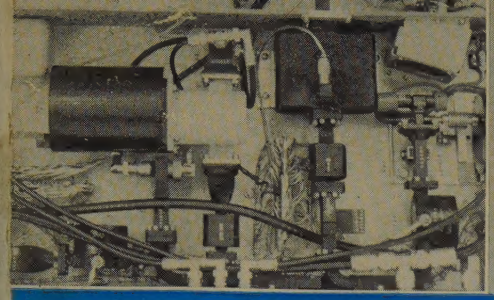

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• SYSTEMS
• TUBES

Wm. P. Harris, Physicist
National Bureau of Standards
114 Engr. Bldg.
Washington 25, D. C.

JULY-AUG. '58
VOL. 1 • NO. 1

the microwave journal

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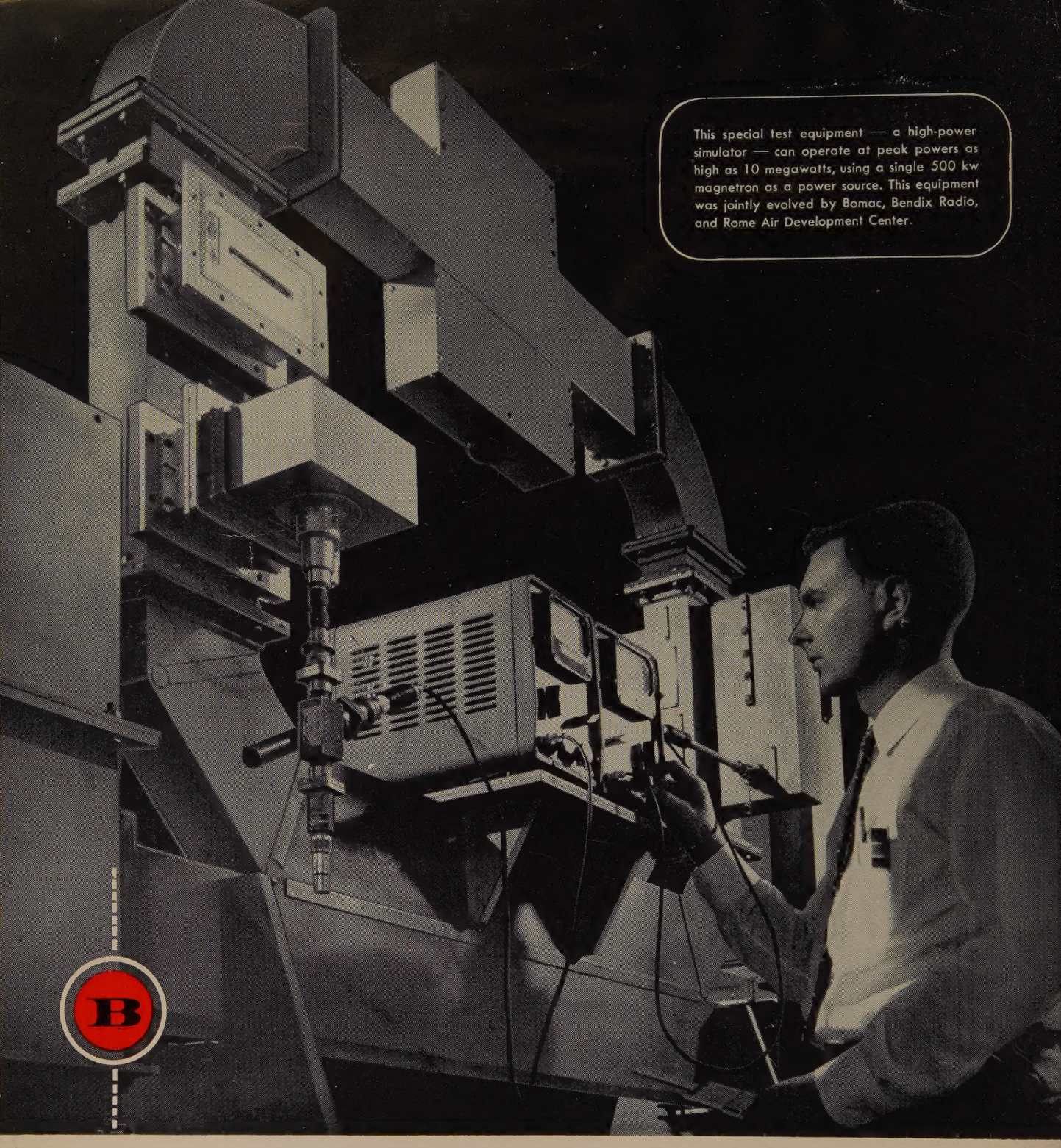

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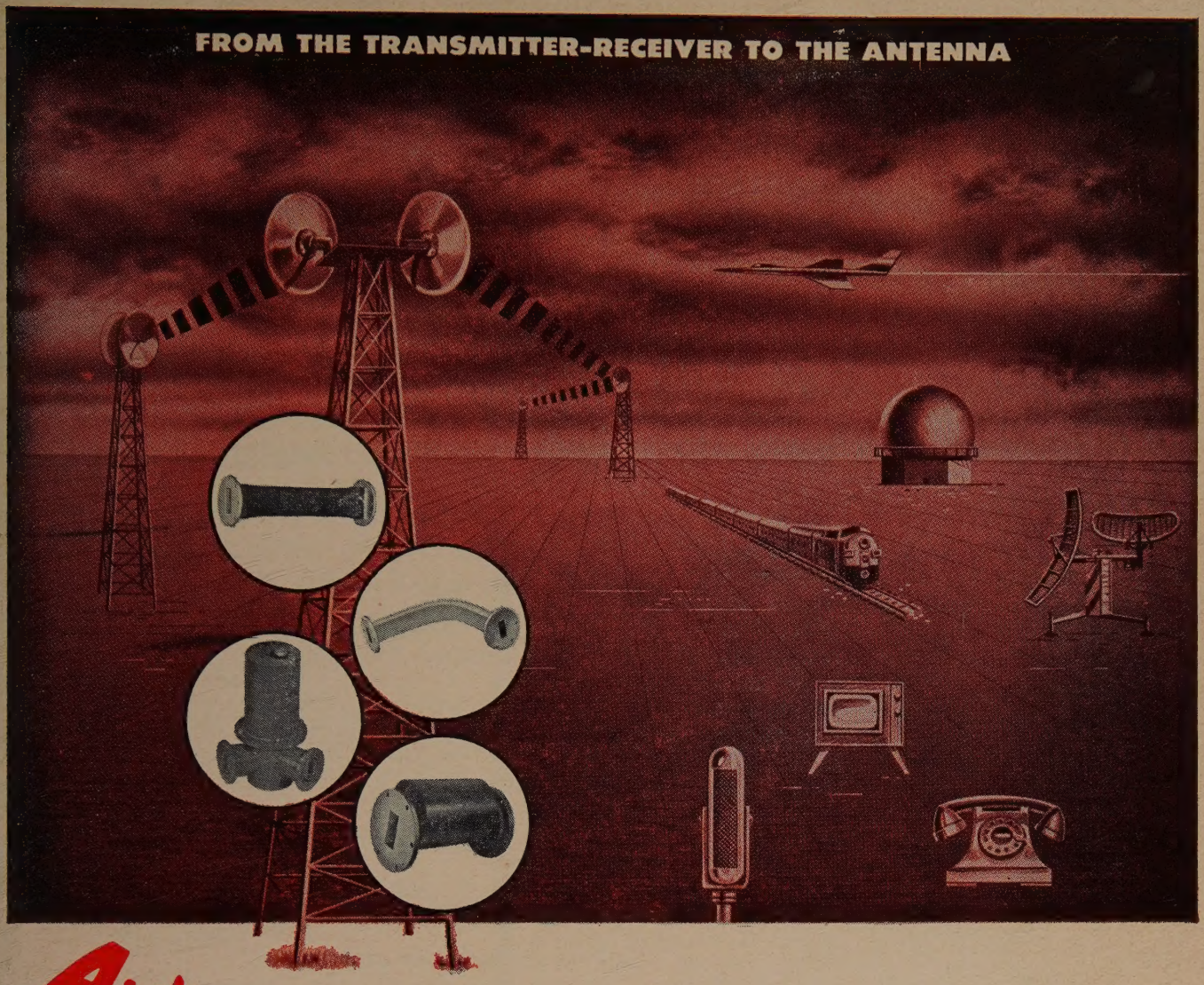

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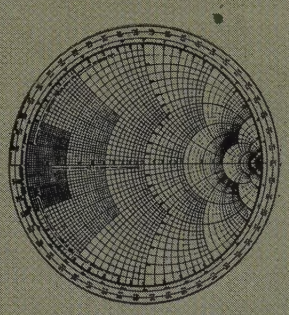

the microwave journal

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COVER PICTURE

Bomarc Missile—Product of combined efforts of many types of engineers, in which the microwave groups have made contributions.

Smith Chart background, symbol of "the microwave journal."

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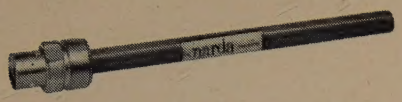

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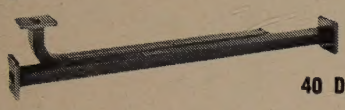

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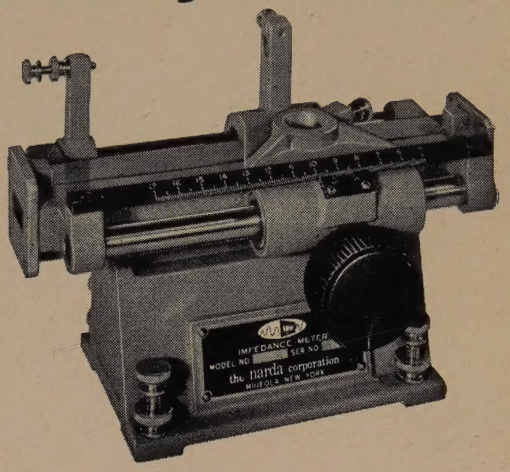

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Publisher's Editorial

This is the first issue of "the microwave journal." Our objective is simply to offer a forum to the industry and be the means of communication for the people in this segment of the electronic field.

We feel that a definite need exists for a full-time magazine devoted exclusively to microwave matters. True, microwave material is published in other respected magazines, but only intermittently, and as a section of the whole electronic complex. In a survey made, the need was expressed for a practical publication for the working engineer in the growing microwave industry. "the microwave journal" is intent in "Saving your Time" by presenting only pertinent matters of interest to the groups working at microwave frequencies in the fields of antennas and propagation, electrons and solid-state devices, systems and components manufacturers.

We will try to bring the finest talent available and communicate their acquired knowledge and skills for the benefit of all. It is our aim to open the pages of "the microwave journal" to this expanding industry with its attendant problems.

We do not pretend to be a profound document but are intent in producing a practical publication as an effective tool for the working engineer. Our Associate Editors and Associates will contribute regularly and give us the benefits of activities in their respective fields.

Additionally, we will include editorials with a business flavor by men in key positions, that will enable the industry to evaluate the thoughts and problems of their fellow associates within the microwave groups. There will be company profiles that should interest people in reading about the phenomenal growth that has been attained by some of the organizations that started in a corner of a barn or of a small group that has now grown to sizable proportions. Biographies of those who have made worthy contributions to the industry will also be featured regularly.

In total, we hope that this will enable the industry to keep in touch with one another, to keep the channels of communication open for the benefit of all.

BIOGRAPHICAL SKETCHES—EDITOR AND ASSOCIATE EDITORS

THEODORE S. SAAD is President of Sage Laboratories, a native of Boston, and resides in Westwood, Mass.

He received his Bachelor's Degree from MIT where he majored in Electrical Communications. Immediately following graduation he spent seven months at Sylvania Electric in Salem and Danvers, Mass., working on fluorescent lamps. In January of 1942 he became a research associate of the MIT Radiation Laboratory, where he worked on microwave plumbing problems in the R-F and Beacon Groups.

In November of 1945 he joined the microwave section of the Submarine Signal Company as a senior development Engineer. In March of 1949 he was employed as Vice-President and Chief Engineer of Microwave Development Labs. In October of 1953 he became an Engineering Specialist at Sylvania in Woburn, Mass. In January of 1955 he helped organize Sage Laboratories. His field of experience includes all types of microwave components.

He has made contributions in the design of directional couplers, cavities, crystal holders, and rotary joints. He was also responsible for the Tripolar Crystal and a coaxial hybrid.

He is a senior member of the IRE and has served on the Administrative Committee of the PGMTT for the last five years. He was one of the organizers and the first Chairman of the Boston chapter of the PGMTT. He was Editor of "The Transactions" for two and a half years and has been appointed Chairman of the Administrative Committee for the 1958-1959 period. He is one of the founders of "the microwave journal."

DR. SEYMOUR B. COHN is manager of the Electromagnetics Laboratory, Stanford Research Institute, Menlo Park, Calif.

He is a native of Connecticut. In 1942 he received a B.E. degree from Yale University, and then joined Harvard University's Radio Research Laboratory, as a special research associate. He left in 1945 to continue studies at Harvard on a fellowship granted by the National Research Council. He received his Ph.D. in Engineering Science and Applied Physics in 1948.

After leaving Harvard, Dr. Cohn joined Sperry Gyroscope Co. at Great Neck, N.Y., as a project engineer, and was later named a research engineer, highest technical title in the company.

Dr. Cohn joined the staff of SRI's Division of Engineering Research early in 1953 as head of the Microwave Group of the Electromagnetics Laboratory, becoming manager in 1957. This group is engaged in research and development of microwave antennas, waveguide and strip-line circuits and components, microwave solid-state devices, and microwave systems.

Dr. Cohn is the author of several chapters on UHF and microwave filters in the book "Very High Frequency Techniques." He also has contributed a chapter on lens antennas for the "Antenna Engineering Handbook" to be published by McGraw-Hill in 1959. He has had more than twenty-five papers published in various technical journals. He holds twenty patents on electronic and microwave inventions and has a number of other applications pending.

He is a member of Sigma Xi, Tau Beta Pi, and the Institute of Radio Engineers. He has served on several IRE committees, and is now a member of the Administrative Committee of the IRE PGMTT. In 1954 the Yale Engineering Association presented Dr. Cohn with their annual award for Advancement of Basic and Applied Science.

DR. HENRY JASIK was born in New York City, on March 12, 1919. He received the degree of B.S. in E.E. in 1938, from the Newark College of Engineering, and the degrees of M.E.E. and D.E.E. from Polytechnic Institute of Brooklyn in 1951 and '53. Dr. Jasik was associated with a number of organizations from 1938 to 1952 as an electronics engineer, and prior to setting up his own firm, was employed by AIL. Since 1952, he has been an independent consultant, and in 1955, he organized Jasik Laboratories, which is presently engaged in work in the VHF and microwave field.

Dr. Jasik has worked on a large variety of antenna problems in both the commercial and military fields. He was responsible for developing one of the first practical embodiments of the spherical Luneberg lens and has also developed the rigorous electromagnetic theory of this type of antenna. Some of his current work is in the field of antennas for radio astronomy, and he has developed the antenna feed systems for a number of the largest radio telescopes in the United States. One of his developments has been the coaxial E-H impedance tuner which has received wide acceptance.

Dr. Jasik is a Fellow of the IRE and has served as past Chairman of its technical committee on Antennas and Waveguides. He is a member of Sigma Xi and Eta Kappa Nu. He is also serving as contributor and Editor-in-Chief of the Antenna Engineering Handbook to be published within the next year by the McGraw-Hill Book Company.

DR. BENJAMIN LAX was born in Hungary on December 29, 1915 and came to this country in August, 1926, living in New York until 1942. In 1937, he went to Cooper Unon on a four-year scholarship, receiving a bachelor's degree in mechanical engineering in 1941. In 1942 he was inducted into the Army as a private and went through OCS.

In 1946 he became a consultant for Sylvania Electric Company prior to entering graduate school that fall at MIT, where he received his Ph.D. in Physics in 1949. From 1949 to 1951 he worked for the Geophysical Directorate of Cambridge Research Center. In November of 1951 he joined the Solid State Group at Lincoln Laboratory, and in 1953 became head of the ferrites group. In 1955 he became head of the Solid State Group. After taking over the Solid State Group, he spearheaded the basic research program on the investigation of energy bands in solids, and with others, carried on theoretical work on galvano-magnetic effects, cyclotron resonance at microwaves and infrared frequencies, and has played a major part in the recent advances in the infrared investigation of conductors in magnetic fields.

Since 1957 he has been Associate Division Head of the Communications and Components Division in charge of the Solid State Program. He is a member of the Steering Committee at Lincoln Laboratory, the American Physical Society and Sigma Xi and is an Associate Editor of the Journal of Applied Physics. He has published over 30 papers and presented approximately 50 talks at various Society Meetings.

MARSHALL PEASE was born in New York City in 1920. He acquired his B.S. in Chemistry at Yale University in 1940 and his M.A. in Physical Chemistry at Princeton University in 1943.

From 1943-45, he was Research Associate in the Radio Research Laboratory at Harvard University. From 1945-46, he was an ensign and Technical Radar Officer in the U.S. Navy.

From 1946 to the present, he has worked for Sylvania Electric Products, Electronics Division, starting in Boston. He was hired as staff consultant, then he became a staff member. He headed the testing group, and then headed the theoretical group which acted as staff to the whole operation. He became manager of Advanced Tube Development at Woburn. The reorganization of Sylvania brought advanced tube work to the Microwave Tube Laboratory at Mountain View, California, where he is presently manager of the Crossed Field Tube Development Department.

He has served on the GETEC Committee on Microwave Devices, was Chairman of the Boston section of the Professional Group on Electron Devices, and is a senior member of IRE.

Since moving to California, gardening has been his hobby. He also has written science fiction stories as a hobby.

When he is not functioning as an administrator, he calls himself a "theoretical engineer," which is a hybrid mixture of engineer, physicist, and mathematician, and disowned by all three.

MICROWAVE HORIZONS

Seymour B. Cohn, *Associate Editor*

WHAT IS THE over-all vitality of microwave engineering? Is this field a dynamic one or has it become stagnant? Is it on the threshold of expansion and new opportunity, or is it already past its peak? Does it offer interest and opportunity to the ambitious engineer today?

Taking a broad view, microwave engineering covers activities on signal sources and amplifiers, on waveguides, transmission lines and components, on antennas and propagation, on instrumentation, and on numerous system applications. Much of this work has been exploited to a high point of development and use in the past two decades. We can see clearly that the future for microwave engineers depends upon the birth of new ideas and upon our alertness to use these ideas to advance our field.

Technological growth is never steady, but comes as a random series of inventive explosions. This is as true of our field as it is of all others. Looking back we can see the various major forward steps clearly, and how their frequency of occurrence has been increasing in recent years. The history of microwave science began in 1888 with Hertz's microwave experiments on dipoles and parabolic reflectors. In fact, this microwave beginning was also the birth of all radio technology. Other important advances were made in the next decade, both in the laboratory and in the mind — for example Lord Rayleigh's mathematical discovery of waveguide mode propagation — but practical applications were not then found. Microwaves appeared valueless, and the surge of effort was transferred to lower frequencies where many important uses were rapidly developed. The 1890's would have been an unlucky time for an engineer hoping to specialize in microwaves!

But in the 1930's attention again turned to microwaves, and this time the results were dazzling. With increasing rapidity great advances were made and quickly exploited, each one altering microwave techniques by enhancing their versatility, scope, and applications. An early example is the development of elaborate circuit techniques involving waveguides, resonant cavities, and many ingenious components. Another example is a succession of breakthroughs in electronic signal sources, such as the magnetron, the klystron, and forward and backward traveling-wave tubes. New advances in microwave antenna design produced remarkable pattern control, scanning characteristics, and bandwidth. We are still in a six-year-old major surge of advance on ferrite applications, and we are in the initial phase of what will doubtless prove to be another major forward surge on solid-state masers and parametric amplifiers. These contributions to microwave techniques have in some cases inspired and in other cases have been inspired by advances in systems applications, such as radar, point-to-point communication, navigation aids, radio astronomy, microwave spectroscopy, and time standards.

Certainly it is safe to conclude that even without a single new major discovery many years would still be needed just to follow the avenues of research, development, and application now open to us. What, then, are the prospects for new discoveries to provide opportunities for us far into the future? I believe, myself, that the prospects are excellent, that the momentum of progress is increasing, and that it cannot be stopped.

The inevitable question is what are the major advances to come? No one, of course, can predict the time or the exact nature of discoveries, but certain generalizations can be made to guide us and to prepare us for the future. We know, for example, that all inventions are based on earlier ideas. In some cases the advance follows close after a step in another field, as in microwave ferrite applications following advances in magnetic materials and the theory of magnetism. In other cases someone discovers that an old idea can be applied in a new and powerful way, as in parametric amplifiers. In both ferrites and parametric amplifiers, solid-state theory has played, and is playing an important role. Because of the great rate of improvement in the understanding of the solid state and the synthesis of new, unusual materials, it is reasonable to expect other important contributions to microwaves from that field. A material for solid-state masers not requiring liquid-helium cooling would greatly expand the utility of that device; a reliable, low-loss ferroelectric material would make possible many applications to the voltage control of microwave components and circuits; and another important reduction in gyromagnetic-resonance bandwidth would improve ferrite devices and make practical electronically tuned filters, gyromagnetic amplifiers, and applications at lower frequencies. Still other unthought-of materials may be found that will have effects on microwave technology that can not now even be imagined.

New applications for microwaves will greatly expand our field. On the horizon we see large-scale use of low-loss millimeter-wave transmission in circular waveguides that will carry thousands of messages simultaneously. We see microwave beams that will make possible communication to space stations, to space ships, and to other planets with high efficiency and a minimum of disturbance from the ionosphere. We see microwave spectroscopy promising to revolutionize the control of industrial processes. And we see microwaves as an important aid in thermo-nuclear power generation, and even possibly as the key that will free the energy of the hydrogen atom to serve mankind. We cannot see past the horizon, but we know that the admirable inventive genius of man will never be satisfied and that there will be new vistas to explore that we cannot predict or imagine now.

If we accept change eagerly, and constantly work to improve our background of knowledge, we may confidently expect to participate in this progress. Looking into the future we may expect just as much excitement of discovery and application as has stimulated our minds and heightened our interest in the past.

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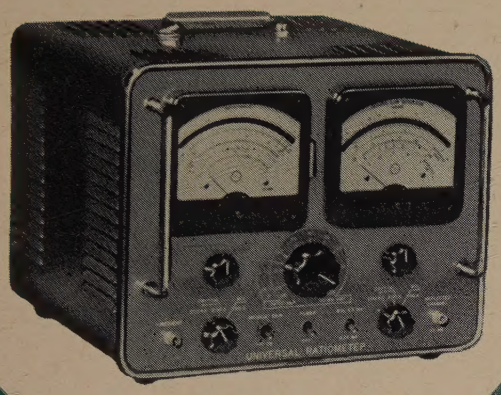

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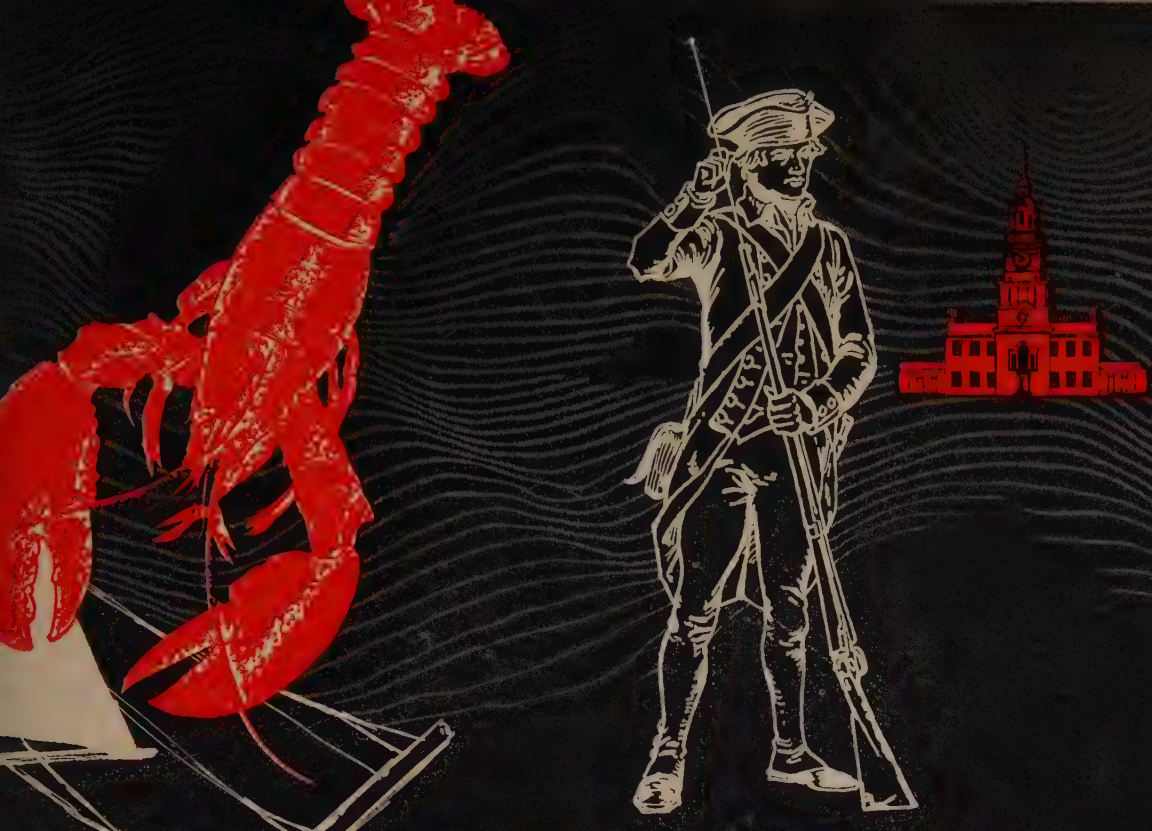
	EMBASSY ROOM	SUNSET ROOM	BOULEVARD ROOM	BALLROOM	VENETIAN ROOM
TUESDAY AUGUST 19 9:30 a.m.-12 n.	Session 1 Computer Applications	Session 2 Reliability I	Session 3 Telemetry	Session 4 Information Theory	Session 5 *Microwave Theory and Techniques I
2:00 p.m.-4:30 p.m.	Session 6 Computer Devices	Session 7 Reliability II	Session 8 Airborne Electronic Devices	Session 9 Circuit Analysis and Design	Session 10 *Microwave Theory and Techniques II
WEDNESDAY AUGUST 20 9:30 a.m.-12 n.	Session 11 *Parametric Amplifiers Masers	Session 12 Modern Management Problems	Session 13 Instrument Tools	Session 14 Circuit Design	Session 15 Audio
2:00 p.m.-4:30 p.m.	Session 16 Industry looks at Fusion Power	Session 17 Transistor Circuits	Session 18 Automatic Control	Session 19 Instrument Systems	Session 20 *Microwave Propagation
THURSDAY AUGUST 21 9:30 a.m.-12 n.	Session 21 Biological Measurement in Space (Evening) Session 23 Analog Computers	Session 22 To be announced (Eve.) Session 24 *Microwave and High-Power Tubes	Session 25 Military Electronics	Session 26 Improved Component Materials	Session 27 *Antenna Arrays
2:00 p.m.-4:30 p.m.	Session 28 Special Electron Devices	Session 29 Human Factors in Engineering	Session 30 *Microwave Ferrites	Session 31 Component Parts	Session 32 Radio and Television Broadcasting
FRIDAY AUGUST 22 9:30 a.m.-12 n.	Session 33 Solid State I	Session 34 Production Techniques	Session 35 *Antennas and Propagation	Session 36 Industrial Electronics	Session 37 Advanced Television Techniques
2:00 p.m.-4:30 p.m.	Session 38 Solid State II	Session 39 Medical Electrons	Session 40 *Antennas	Session 41 Engineering Writing and Speech	Session 42 Communications Systems & Vehicular Communications

*Of special interest to the Microwave groups.



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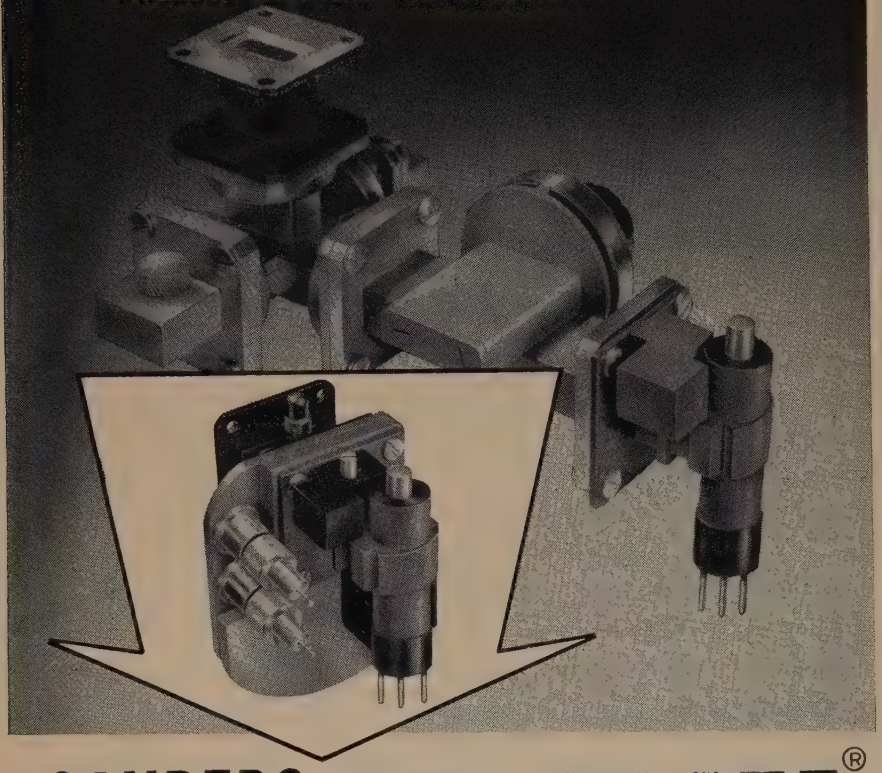

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Letters to the Editor

We invite comments and letters to the editor each month. We are appreciative of these unsolicited letters that arrived and were instrumental in helping us form our decision to start "the microwave journal."

. . . I would like to congratulate you on starting such an important venture as *"the microwave journal"* and I certainly wish you all the success with your new enterprise. . . .

HENRY MAGNUSKI
Motorola, Inc.

•

. . . May I suggest that there is a great need at the moment for tutorial papers particularly in the field of microwaves. To many people this field is still very strange. Much needs to be said about basic principles and much needs to be said about how the many new gadgets that come from these principles really work. Above all much simplification is needed.

With my very best wishes in your new undertaking, I am

GEORGE SOUTHWORTH

•

. . . We welcome the announcement of your new journal, and are pleased to be included among your Charter Subscribers. There has long been a need for a trade journal to serve the microwave industry. I am very pleased that the magazine is now coming out, and that it is being directed by a microwave engineer.

Our very best wishes for your success.

WILLIAM A. BOURKE
Vice President
Narda Microwave Corp.

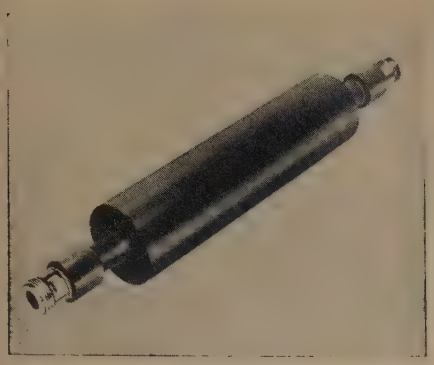
•

. . . I was very glad to learn of your proposed publication, *"the microwave journal."*

Since publications of this nature are of particular interest to us, I would appreciate being placed on your mailing list.

MARVIN L. INGALSBE
Head, Antenna Section
Lockheed Aircraft Corp.

For Ground and Airborne Installations — New Coaxial Ferrite Isolators Available



Airtron, Inc.*, Linden, New Jersey announces a new line of coaxial ferrite isolators for applications in 3/8" and 7/8" coaxial systems.

The 3/8" coaxial ferrite isolator has been designed to operate over the frequency range of 2000 to 4000 mc/s providing an isolation tion of 10 db nominal with a maximum insertion loss of 1 db, and a maximum VSWR of 1.30. The power handling capability is 5 watts CW with a 2:1 load mismatch. Overall length of the unit is 10 inches.

Two units have been designed for 7/8" coaxial systems and cover a frequency range of 2350 to 3600 mc/s and 3500 to 5000 mc/s respectively. A minimum isolation of 10 db is afforded with a maximum insertion loss of .8 db and a maximum VSWR of 1.25. The average power capacity is 300 watts CW with a 2.5 load VSWR. Cooling fins are provided on the 7/8" coaxial isolator for rapid dissipation of heat, allowing operation at the high average power levels indicated. The overall length of these units are 14 3/16 inches.

The standard 3/8" coaxial ferrite isolator has type "N" female connectors on both the input and output, whereas the 7/8" unit is equipped with any combination of male and female type "LT" connectors. Both units can be supplied with combinations of these or other connectors as required.

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— Dr. Henry J. Riblet

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COLIN BOWNESS

Colin Bowness was born in London, England, on October 26, 1929. He attended the Northern Polytechnic, London, in the Department of Physics where he received his B.Sc. degree in 1951. From 1951 until 1957 he worked in the Microwave Laboratory of the Electrical and Musical Industries, Feltham, England carrying out research and development on a wide range of microwave components and systems.

During the period 1951-1956 he was engaged in part-time research work in the Physics Department of Birkbeck College, London, studying the scattering of electrons and positrons. For this work he received his PhD degree from the University of London in 1956. In 1957 he joined the Raytheon Manufacturing Company where he is at present the Technical Director of the Special Microwave Device Group engaged in the design and development of ferrite components.

Dr. Bowness is an associate of the Institute of Physics and a member of the IRE.

TORE N. ANDERSON

Tore N. Anderson, Vice-President and Director of Engineering, Airtron, Inc., is in charge of the Microwave Electronics Division.

During the war, Mr. Anderson served with the Engineering Research and Development Agency, Fort Belvoir, Virginia, as a project officer on underwater mine detectors and as Chief of the Laboratory and Test Section.

After the war, he was employed as Engineer-in-Charge of radio frequency measurements at Electrical Testing Laboratories in New York.

Mr. Anderson has been associated with Airtron, Inc. since 1948. In 1951, Mr. Anderson was appointed Chief Engineer of Airtron, Inc. In 1953, he was appointed to the Board of Directors and made Vice-President and Chief Engineer and was made Director of Engineering in 1956.

Mr. Anderson is a member of Tau Beta Pi, AIEE, APS and a senior member of the IRE. He organized the Northern New Jersey Chapter of the IRE PGMTT. He is now on the Administrative Committee and Editorial Board of the PGMTT.

Mr. Anderson holds a group of patents covering the design and application of electronic components.

DANA W. ATCHLEY, JR.

Dana W. Atchley, Jr. received his B.S. from Harvard College in 1939. He worked in Cruft Laboratory at Harvard University from 1939-40. From 1940-41, he was Research Engineer at Hygrade-Sylvania Corporation. He received a letter of commendation for his work as Lieut. Com., USNR, Staff, in the NRL during World War II. From 1945-47, he was Government Sales Manager in the Electronics Division of Sylvania Electric Products Inc. He was Sales Manager and then Director of Engineering, Tracerlab, Inc., from 1947-51. In 1951, he became Co-ordinator of Technical Research for United Paramount Theaters, Inc. He joined Microwave Associates, Inc. as President in 1952.

He is the author of several technical articles and the holder of several patents. He is a member of the IRE. Since 1933, he has been an active radio amateur. He is also the director of Power Sources, Inc.

GUEST CONTRIBUTORS

MICROWAVE FERRITES

and their application

By DR. COLIN BOWNESS
RAYTHEON MANUFACTURING COMPANY
WALTHAM, MASSACHUSETTS

INTRODUCTION

The use of ferrite devices for microwave applications has increased tremendously in the last few years, and a further increase appears certain as better devices are developed and new systems dependent upon such devices are invented. As in other expanding fields, there is much literature on specific items and problems but almost none intended to give system design engineers a good over-all picture of the devices currently available. The purpose of this paper is to fill this need.

Only occasionally can the systems designer formulate performance specifications for a ferrite device and leave the design problems to be solved by the ferrite specialist in the best known manner. More often the systems designer must know what is feasible in the present state of the art before he is in a position to write specifications. For this reason, all available performance data will be included in the discussion of each device. Since this information will tend to become obsolete with improved techniques, an attempt will be made to predict what may be expected in the immediate future.

Basic theory will be presented only where necessary for an understanding of practical applications. Readers who would like to go more deeply into theory are referred to the excellent articles by C. L. Hogan and B. Lax* in the Ferrite Issue of the PROCEEDINGS OF THE IRE. October, 1956.

Ferrites are magnetic materials, ceramic in nature, which are composed mainly of oxides of metals such as iron, nickel, cobalt, magnesium, manganese, and aluminum. A recently discovered class of ferrites, known as garnets, promises to extend the range of magnetic properties available.

*Associate Editor of *the microwave journal.*

MICROWAVE FERRITES

Microwave ferrites differ from conventional metallic magnetic materials in two basic ways: they are non-conducting, and they exhibit little hysteresis loss at microwave frequencies. Such materials have made possible two classes of microwave devices, reciprocal and non-reciprocal, which have considerably extended the possibilities of microwave systems.

In the reciprocal class an externally applied magnetic field is made to control the amplitude or phase of a microwave signal. In the non-reciprocal class a fifth type of circuit element has become available in which the amplitude or phase of a signal depends upon the direction in which the wave travels through the device. The commonest example is the ferrite isolator, which strongly attenuates a wave traveling in one direction while leaving a wave traveling in the opposite direction substantially unaffected.

Apart from the general properties already mentioned there are three more properties of fundamental importance to the ferrite device designer. These are the saturation magnetization, the line width and the Curie temperature.

Saturation Magnetization

This defines the field required to saturate the material to align the direction of magnetization of the domains. This is important since it determines the lowest frequency at which the material is usable (see Frequency Limitations, below). Saturation magnetization is also important because it affects the external magnetic field required in such devices as isolators, though this is a second-order effect.

Line Width

Many ferrite devices employ the ferromagnetic phenomenon of resonance, which comes from the interaction of an rf magnetic field with the electrons in the material spinning about their own axes. The electrons, being charged particles, simulate a current flowing through a coil and thus have a magnetic vector along their axes. This magnetic vector tends to align itself with an applied magnetic field but in fact precesses about the field at a rate determined by the field strength. When the rate of precession becomes equal to the frequency of the microwave signal, resonance will occur and absorption will take place under suitable conditions. The line width is the field strength over which resonance occurs at a given frequency. Thus a broad line width indicates a broadband device, and conversely for a narrow line width. However the broad band is gained at the expense of a reduced absolute value of the loss for a given configuration of ferrite and waveguide.

Curie Temperature

This is the temperature at which the ferrite loses its magnetic properties. This loss occurs gradually as the temperature rises, i.e., the saturation magnetization will reduce from its value at room temperature to zero at the Curie temperature of that particular ferrite. Generally this degradation becomes more rapid as the Curie temperature is approached.

Curie temperatures range from about 600°C for nickel ferrite down to about 100°C for some ferrites made to have some special property such as narrow line width or low saturation magnetization.

FREQUENCY LIMITATIONS

Losses in microwave ferrites tend to increase as frequency decreases. When the ferrite is in a small applied field or is completely unmagnetized, a loss may occur. This loss is referred to as low field loss and is due to the microwave magnetic field causing rotational resonance of some domains which are

subjected to suitable anisotropic fields existing within a polycrystalline ferrite. The lowest frequency at which this loss becomes negligible is proportional to the saturation magnetization. Thus, for low-frequency applications, a ferrite with a low saturation magnetization is desirable.

Taking the resonance isolator as a typical example, the back-to-front ratio (i.e., the ratio of the db loss in the two directions) is given by the approximate formula

$$\text{back-to-front ratio} = \left(\frac{4\omega}{\gamma\Delta H}\right)^2$$

in this ω is the frequency in Mc/s, γ is a constant for the ferrite and is about 2.8 Mcs/oersted for most ferrites and ΔH is the line width. Hence for a given ferrite the back-to-front ratio of an isolator may be expected to reduce as the square of the frequency.

For a ferrite device operating well below or above resonance, the figure of merit is taken as the ratio of the phase shift or Faraday rotation to the insertion loss. In either case one finds:

$$\text{Figure of merit} = \left(\frac{2\omega}{\gamma\Delta H}\right) \text{ radians/neper.}$$

Here the figure of merit decreases in proportion to the frequency, and in both cases low-frequency operation is enhanced by the use of a ferrite having a narrow line width.

At high frequencies, low field loss is no longer a problem but the magnetic fields required for resonance become very large. The field for resonance is given approximately by

$$H_{res} = \frac{\omega}{\gamma}$$

and since γ is substantially constant, the magnetic field increases in proportion to the frequency. Fortunately this effect is somewhat compensated as far as magnet size is concerned because the waveguide becomes smaller and the gap over which the field is required is therefore less.

HIGH-POWER LIMITATION

As microwave power tubes become more efficient, the need for ferrite devices capable of operating at high power levels becomes increasingly important. The limitations of ferrite devices come from two distinct sources, heating effects and non-linear effects.

Heating Effects

As previously mentioned, ferrites gradually lose their magnetic properties as they are heated towards their Curie temperature. All ferrite devices have some insertion loss, usually less than 1 db, and ferrite isolators have to absorb some reflected power. Figure 1 shows the percentage of power absorbed for insertion losses up to 3 db, and figure 2 shows the power reflected by mismatches having VSWR's up to 3: 1. If the average power is known the total amount of heat to be dissipated by a device such as an isolator may be calculated. Clearly the higher the Curie temperature the greater the power handling capability; but beyond a certain limit, set in part by the physical size of the unit, some form of forced cooling will be necessary.

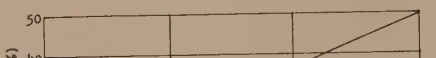


Figure 1 — Graph of Insertion Loss Against Power Absorbed

Figure 2 — Graph of VSWR Against Power Reflected

Non-linear Effects

Most passive microwave devices behave in the same manner regardless of the peak power applied but ferrite devices may have different performance at high power than at low power. When the rf magnetic field in a ferrite device exceeds a certain critical value, its behavior begins to alter radically and the device is said to become non-linear. The cause of this non-linearity is in the disturbance of the uniform precession by strong rf magnetic fields. It is thus impossible to avoid, since ferrite devices depend on such interaction. However careful design can minimize such effects and produce ferrite devices capable of handling megawatts of peak power.

Whereas heating effects depend only upon the average power, non-linear effects depend solely on the peak power. The precise power level at which non-linearity begins will depend on the type of device, the applied magnetic field, and the line width of the ferrite material being used. Generally, the smaller the line width, the lower the power level for the onset of non-linearity; a similar rule is found for applied field.

ISOLATORS

The one-way transmission lines known as isolators are undoubtedly the most common ferrite devices. Their great value lies in their ability to isolate a generator from a load. Much has been written on the change in frequency and power output of klystrons and magnetrons caused by variations in the load impedance. With such changes the generator may stop oscillating, change mode, or change its frequency spectrum, while in addition, in the case of high-power tubes, a reflected wave may permanently damage the tube.

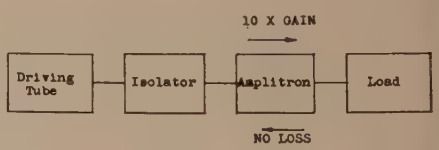


Figure 3 — Amplitron Chain

With the recent advent of high-power amplifying tubes (such as the Raytheon amplitron), the isolator becomes not only desirable but necessary. Figure 3 illustrates the reason for this. Suppose the load has a 2: 1 mismatch; then figure 2 shows that 11% of the power is reflected. Since the incident wave had already been amplified by a factor of 10, this implies that the reflected power at the driving tube would be about equal to the output power. That is, were it not for the isolator, the tube would be, in effect, trying to operate while looking into a short circuit. The requirements for such an isolator are stringent since it must be capable of absorbing a power about equal to that of the driving tube, which may be several kilowatts average in certain cases. Also the peak power may be several megawatts and this may cause degradation due to non-linearity.

At the other extreme, isolators are required for use with tubes whose output is less than one watt. If size and weight are at a premium, resonance isolators no longer offer the best solution.

In order to clarify the situation, the isolators currently available will be divided into three groups according to approximate power handling capacity. The precise power handling capacity will of course depend on the particular design and the presence or absence of cooling.

Low-Power Isolators

(up to 5 watts average transmitted power)

Faraday Rotation Isolator

The most versatile isolator for low-power levels is probably the Faraday rotation type. If a plane-polarized wave is propagated through a circular waveguide containing an axial ferrite rod, the plane of polarization can be rotated by applying a longitudinal magnetic field to the rod. The degree of rotation will depend on the length and size of the rod and upon the strength of the applied field, but the *sense* of rotation will depend only upon the direction of the applied field.

Figure 4 illustrates how this effect can be used to make an isolator if the rotation is 45°. The input E vector is unaffected by the first resistive vane since it is perpendicular to it. After passing through the ferrite loaded section, this vector has been rotated 45° as shown, and is then perpendicular to the second resistive vane so that it passes out of the device unattenuated. However, a reflected wave entering from the output port will be rotated 45° further in the same direction and will be absorbed in the resistive vane at the input end.

Such a design has the following disadvantages: The resistive vanes have to absorb the power — hence there is a power limitation. Secondly, maximum isolation is limited to about 30 db due to ellipticity generated in the ferrite and to deviation from exact 45° rotation. On the other hand, figure 5 shows that extremely useful performance is possible with such a device even when space and weight are severely limited; this unit, only 0.7 in. long and weighing less than 3 oz., gives 30 to 0.3 db at midband. For such applications this type of isolator is without peer.

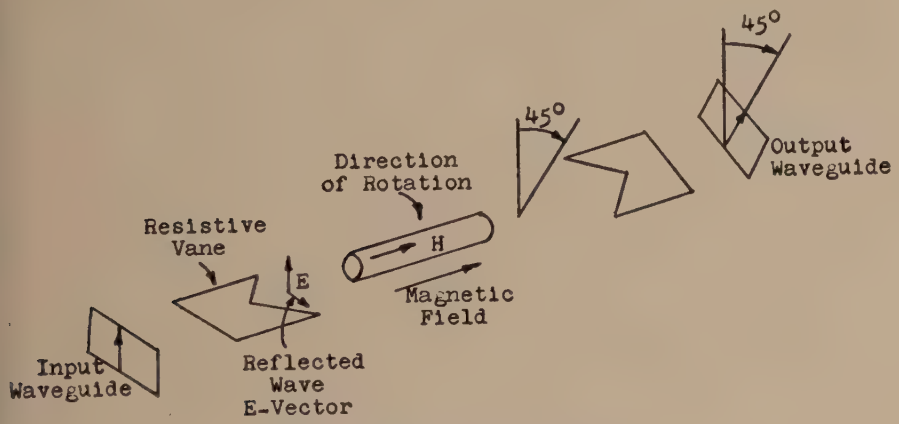


Figure 4 — Faraday Rotation Isolator

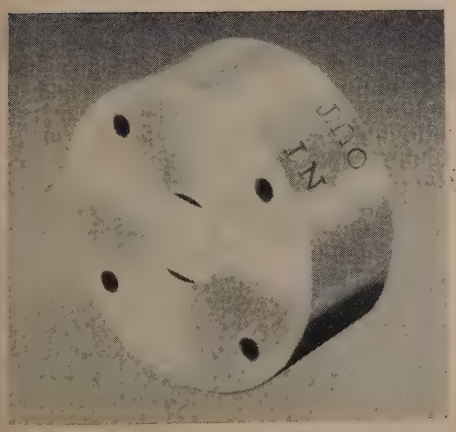


Figure 5 — MODEL IKEL2
A miniature Ke-band Isolator

Frequency	12.5 — 14.5 Kmc/s
Power transmitted	5 W max.
Isolation	17 db min.
Insertion Loss	0.5 db max.
VSWR	1.3 max.
Length	0.7 inches
Weight	3 oz.
Temp.	— 55°C. to + 130°C.
Power	5 watts transmitted

The input and output waveguides are at 45° in this example, but any other orientation is possible by the use of twist irises. Such irises do not increase the length or weight substantially but do reduce the bandwidth over which a given VSWR can be maintained. However, when packaging a system it may be possible to utilize such a twist, and the isolator may replace a twist section without an increase in overall length. Figure 6 shows typical characteristics for these miniature isolators at X-band. Improved performance can be obtained only with an increase in length and weight.

When packaged next to a conventional klystron, the Faraday rotation isolator has the advantage that any stray magnetic field will be perpendicular to the electron beam and of much smaller magnitude than that of a resonance isolator; therefore, no interaction is likely to occur. Since Faraday rotation reaches a maximum as the ferrite is saturated, usually below 200 oersteds, the unit can be designed to be fairly insensitive to changes in the applied field; this is never the case with resonance isolators. This insensitivity enables operation over broad temperature ranges with a degradation of a few decibels in the isolation only.

The low-frequency limit for rotational devices is higher than for resonant devices. This is because the low-field losses increase and the field at which resonance occurs decreases until these two losses overlap. There is no low-field region where the insertion loss is low enough for good performance of a rotational device. At about 3,000 mc the minimum insertion loss would probably be 1 db with a low-saturation magnetization ferrite. Operation down to 1,000 mc might be possible with higher insertion losses; and by exceeding the field strength required for resonance, operation at even lower frequencies is feasible. Nevertheless, the figure of merit indicates that a 45° rotator using a 50-oersted line-width material at 1000 mc would have 0.5-db loss.

The Faraday rotator is not suitable for high-peak-power operation since non-linear effects may be expected at relatively low peak powers in this geometry; with careful design, however, peak powers of 100 kw and above can be satisfactorily handled. The most suitable material for these devices is magnesium manganese fer-

Figure 6 — Miniature X-band Isolator Performance

	SINGLE FREQUENCY		10% Bandwidth	
Orientation of input and output	45°	Any other angle	45°	Any other angle
Isolation db	30	30	20	18
Insertion loss db	0.5	0.6	0.7	0.8
VSWR	1.1	1.1	1.3	1.4
Length (inches)	1	1	1	1
Minimum Weight (oz.)	2	2	2	2

rite because it has extremely low dielectric losses and a reasonably high saturation magnetization to which rotation is proportional.

Field Displacement Isolator

This is another type of isolator in which the power is absorbed in a resistive vane. It can be used in either circular or rectangular waveguide. Figure 7 illustrates the latter application, in which operation depends upon the differing displacement of the plane of maximum E field within the waveguide for the two directions of propagation. The curves show the magnitude of the electric field across the waveguide in each direction. It is evident that the resistive vane will not affect the forward wave whereas the reverse wave will be strongly attenuated.

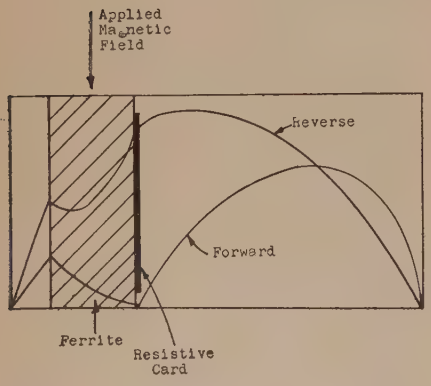


Figure 7 — Field Displacement Isolator

For effective operation a low-dielectric-loss ferrite is required. Perhaps the best low-loss material is manganese magnesium ferrite, which permits excellent back-to-front ratios. However, considerable degradation occurs when the temperature of operation varies by as little as 30°C. Ferrites of higher Curie temperatures are less affected but usually have higher insertion losses.

The magnetic field required for field displacement isolators is of the same order as for rotational isolators. The average power handling capacity, low frequency, and peak power limitations are also similar.

The performance of a short unit of the field displacement type is similar to that of a rotation isolator but is capable of higher isolation if the length is increased. However, the degradation caused by temperature changes cancels out this advantage. Moreover, two or more rotation units can be joined in line, with suitable spacing, if more than 30 db of isolation is required.

Medium-Power Isolators

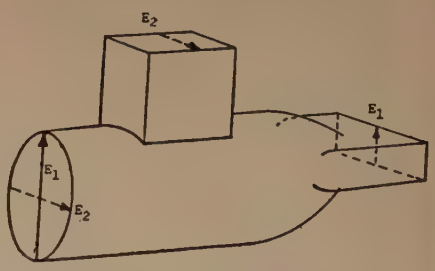
(up to 250 watts average transmitted power)

Three types will be considered: modified Faraday rotation isolators, resonance isolators using an E-plane geometry, and coaxial isolators.

Modified Faraday Rotation Isolators

The limitations of rotation isolators using resistive vanes may be overcome to some extent by using a two-mode transducer at one or both ends of the ferrite loaded section. Such a transducer is shown in figure 8. If the wave in the circular waveguide is polarized in the direction indicated by the arrow E_1, it will not couple to arm 2 and will pass out of arm 1. If the wave in the circular waveguide is polarized in the direction shown by E_2, it cannot propagate out of arm 1, since this waveguide would be cut off for such a mode. However, by suitable matching this wave can be made to leave the junction by arm 2, as shown. Referring back to figure 4, it is seen that

Figure 8 — Two-Mode Transducer



replacing the resistive vane of the input with such a transducer will not affect the transmitted wave but will divert the reflected wave into a side arm where it can be absorbed in a matched load.

This arrangement increases the average power handling capacity of a Faraday rotation isolator to the point where losses in the ferrite become important. Such losses heat the ferrite and tend to alter the rotation from 45°. Unfortunately, the low-loss manganese magnesium ferrite used for such devices has a Curie temperature of only 300°C. Ferrites of higher Curie temperature could be used but would probably have higher insertion losses; thus any improvement would be partially canceled out.

The other limitations, such as nonlinearity at high peak powers and a maximum attainable isolation of about 30 db, still apply for the reasons given for low-power rotational isolators.

Resonance Isolators
(E-plane geometry)

The configuration of such an isolator varies considerably, but figure 9 shows two common forms. In the basic form (figure 9a), the ferrite is located approximately one-quarter of the way across the waveguide, in such a plane that the rf magnetic field is circularly polarized. Since the rf field rotates about the direction of the applied DC field resonant absorption takes place as described under Line Width, above, depending on the frequency, DC field, and direction of propagation.

Figure 9b illustrates a similar isolator which employs dielectric loading for improved performance. The presence of the dielectric displaces the plane of circular polarization and thus the position of the ferrite, but the principle of operation is the same. In other designs the ferrite slab may be split in two and each piece bonded to

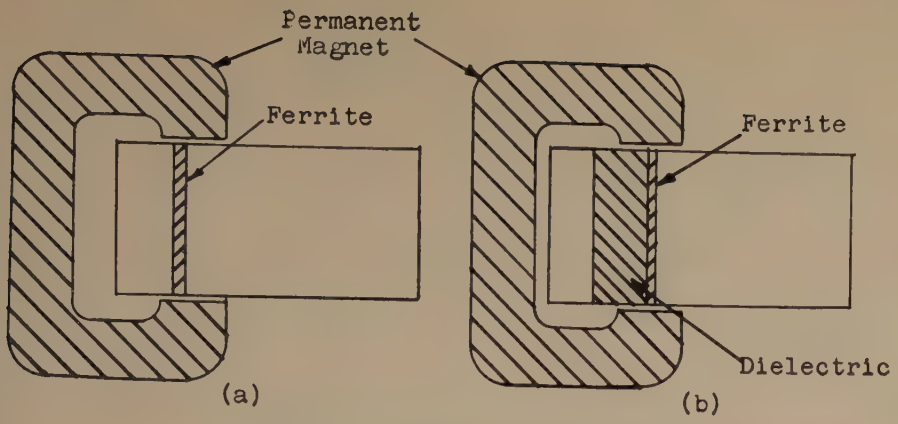


Figure 9 — E-Plane Resonance Isolator

the waveguide wall; again, dielectric loading may be employed to improve the performance. Yet another design may use ferrite and dielectric in a ridged waveguide for increased bandwidth.

Such devices are limited in their power handling capacity because the absorbed power appears as heat in the ferrite and cannot efficiently be removed, ferrite being a poor thermal conductor. Figure 10 shows the typical performance of a C-band isolator employing dielectric loading.

Very broad-band units of fairly compact design can be made by a combination of these medium-power techniques. Performance of 30 db to 1 db from 8.2 to 12.4 kmc in an isolator only 6 in. long has been reported, and a unit giving 75 db to 1 db over the band 8.0 to 14.0 kmc seems feasible.

The magnetic field required by isolators having E-plane ferrite geometry is higher than for rotational devices, but the fact that the ferrite completes, or tends to complete, the magnetic loop helps to reduce the size of the magnet. Since the waveguide can be made of aluminum if required, the magnet is the main source of weight.

The low-frequency limit of isolators of this type is about 2000 mc because at this frequency the resonance field becomes insufficient to saturate the ferrite and remove low-field losses.

Coaxial Isolator

In ordinary coaxial line the fundamental TEM mode has no region where a circularly polarized magnetic field exists. However, by the introduction of dielectric in an asymmetrical manner, the necessary region of circular polarization can be formed. Figure 11 shows the cross section of

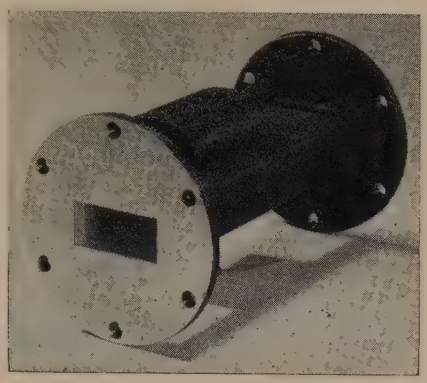


Figure 10 — MODEL ICM7
A C-band medium Power Isolator

Frequency	7125 — 7650 mc/s
Power transmitted	25 W typical
Isolation	25 db min.
Insertion loss	0.5 db max.
VSWR	1.1 max.
Length	4 inches

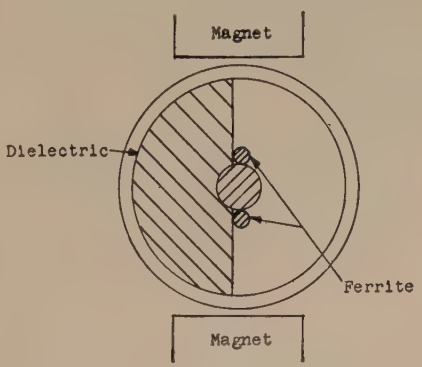


Figure 11 — Coaxial Isolator

such a loaded coaxial line and the location of the ferrite.

The advantage of this device lies in its large bandwidth and in its small size, particularly at low frequencies where waveguides, and thus isolators, become quite large. An isolation of 10 db and insertion loss of 1 db have been achieved over the octave band 2.0 to 4.0 kmc. Over the range 1.7 to 2.0 kmc, better than 20: 1 db has been achieved, and operation at lower frequencies has been reported.

The use of coaxial isolators is limited to the lower frequencies not only because their size advantage is confined to this range but also because at higher frequencies coaxial line is more difficult to use. The difficulty of simply joining two coaxial lines together without mismatch increases with frequency, as does the possibility for higher-order modes to exist.

Although, due to the air gap, the magnetic field and the magnet required by the coaxial isolator is greater than for the E-plane geometry isolator, this very fact enables the coaxial type to operate at lower frequencies than the latter. The reason is that the ferrite is magnetically saturated before the field required for resonance is reached. By the use of low-saturation magnetization and narrow-line-width ferrites such as garnets, low-power isolators in the UHF region have been reported.

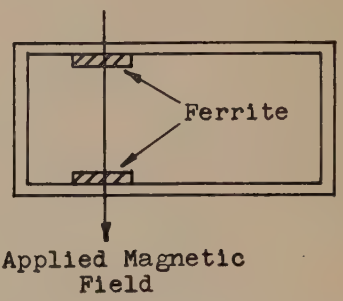


Figure 12 — Typical High Power Isolator

High-Power Isolators
(above 250W average power)

H-plane Resonance Isolator

For high-power operation an isolator similar in design to that shown in figure 12 is generally used. Slabs of a dielectric capable of withstanding high temperatures are sometimes placed near the ferrite to improve the performance. The use of such flat slabs of ferrite, known as H-plane geometry, is dictated because it enables the ferrite to be cooled efficiently.

Cooling may be by convection, forced air, or liquid means, depending on the power dissipation of the isolator. For very-high-power operation the ferrite must be in good thermal contact with the waveguide wall, requiring special techniques.

Due to the demagnetizing effect of the ferrite slabs and the large air gap, a fairly bulky magnet is often needed to provide the field required for resonance. However, this high applied

field helps saturate the ferrite and consequently enables such isolators to operate at lower frequencies than most other devices. In order to reduce magnet size at low frequencies it is possible to reduce the waveguide height considerably, since breakdown is not usually a limiting factor. Figure 13 indicates the performance of a very-high-power L-band isolator of compact design using liquid cooling and half-height waveguide to reduce the size of the magnets. By the use of low-saturation-magnetization ferrites, operation of such isolators has been achieved down to a few hundred megacycles.

At higher frequencies a back-to-front ratio of 30: 1 over a 10% frequency band is possible in a high-power isolator having a peak power handling capacity 75% that of the undisturbed waveguide. At still higher frequencies, above about 40 kmc, the required field becomes so large that permanent magnets of the desired stability become impracticable.

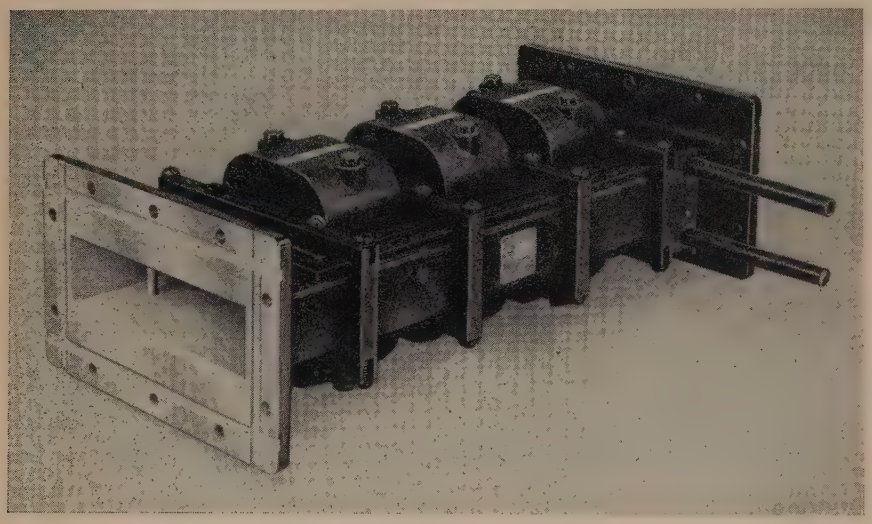


Figure 13 — MODEL ILH2
A high power L-band Isolator

Frequency	1250 — 1350 mc/s
Peak Power	3 MW max.
Average Power	2.5 KW min.
Isolation	11 db min.
Insertion Loss	0.55 max.
VSWR (including transition)	1.15 max.
Length (including transition)	17 inches
Weight (including transition)	34 lbs.

Miscellaneous Isolators

For special applications, isolators have been designed to operate in helical and strip line, the former being of particular interest in traveling-wave tube design. Also, variations of the field displacement isolator have been demonstrated in circular waveguide.

PHASE CHANGERS

Just as ferrite devices can change the amplitude of a microwave signal, so can they change the phase in either a reciprocal or non-reciprocal manner.

Transverse Field Phase Changers

A typical high-power phase shifter will be similar to a high-power isolator in form although the magnetic field will usually be much smaller. If the ferrite is placed to one side of the waveguide, the phase shift will be different for the two directions of propagation. If, however, the ferrite is located centrally the phase shift will be reciprocal. Since the phase shift varies with the applied field in a similar manner to the Faraday rotation, variable phase shifters will require magnetic fields up to a few hundred oersteds.

This low field requirement implies the same low-frequency limitations as mentioned for Faraday rotation devices. At about 3000 mc, the minimum insertion loss of a practical phase shifter of 180° would be about 1 db; however, in certain types of phase shifters this can be overcome by operating with a magnetic field greater than that required for resonance. A typical example might be an S-band 90° non-reciprocal phase shifter which is a valuable circuit element for use in circulators. Such a unit may be designed to use a ferrite above its resonance but the magnet required would be relatively large. Some improvement in performance might be obtained by dielectric loading but a better solution would be to use a ferrite having low saturation magnetization and narrow line width.

Dielectric loading techniques are used in much the same manner as in isolator design, the increased phase shift enabling smaller insertion losses to be obtained and smaller magnets to be used. Once again E-plane ferrite geometry may be used at low or medium power with greatly reduced magnet requirements.

Longitudinal Field Phase Changers

These are essentially low- or medium-power phase shifters and can take a variety of forms. Possibly the simplest is that illustrated in figure 14. It consists of a ferrite rod placed along the axis of a waveguide with a coil surrounding the waveguide to supply the necessary longitudinal field. Such a phase shifter is reciprocal and can readily be modulated.

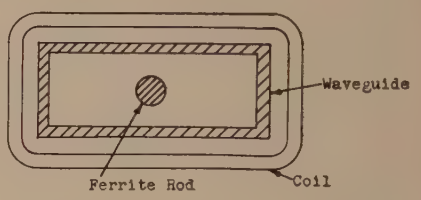


Figure 14 — Rectangular Waveguide Phase Changer

Most other longitudinal field types use ferrite in circular waveguide. One simple type is the bucking rotator in which two Faraday rotation sections with opposing directions of rotation are placed together so as to keep the total rotation zero for all applied fields. This too, is a reciprocal device.

A non-reciprocal phase shifter can be made by first changing from linear to circular polarization by means of quarter-wave plate and then passing the wave through a ferrite phase-shift section. A second quarter-wave plate converts the wave back to plane polarization. Once again the relatively small longitudinal field required permits convenient modulation.

At X-band and higher frequencies, 90° phase shifts will usually have insertion losses less than 0.5 db for either transverse or longitudinal field type. As frequency is lowered the insertion loss will increase to about 1 db at S-band. Operation at lower frequencies is possible by using the

transverse field design and operating with a field greater than that required for resonance.

Frequency Modulators

If a wave is subjected to a change of phase which is a function of time, frequency modulation will result. A phase changer such as that shown in figure 14 can be modulated sinusoidally, for example, by applying a sine wave to the coil. There will be no frequency shift at the maxima and minima of the applied wave, when the phase change as a function of time is zero. Conversely, maximum frequency shift occurs at maximum rate of change of phase. Thus, a given frequency deviation may be obtained by adjusting the amplitude of the applied modulating waveform.

Due to the large field required by high-power transverse-field phase shifters, considerable driving power may be needed to make high-power frequency modulators. However, at medium and low rf powers, frequency modulators are practical devices within the limitations of the phase shifters themselves.

Single-Sideband Generators

This is a special class of frequency modulator in which the frequency spectrum of a signal is translated by a given amount. A very simple form of single-sideband generator is a phase shifter which changes phase linearly by 2π in a time t causing a frequency change of $\frac{2\pi}{t}$. A sawtooth waveform of period t with rapid flyback can be used if the total phase change is 2π. An alternative method is to use a rotating ferrite half-wave plate between two circular polarizers and apply a continuously rotating magnetic field to the ferrite section from crossed coils. Both methods have been employed successfully for frequency translations below 100 kc. However, above 100 kc the practical difficulties of both methods become considerable and efficiency rapidly suffers both in terms of driving power and freedom from unwanted sidebands and carrier.

Lately, more complex methods using Faraday rotation have enabled single-sideband generators to operate with frequency translations of 10 mc and above. At X-band a conversion efficiency of 6 db at 2 mc with a driving power of a few watts is possible. Such devices have the same rf-power and low-frequency limitations as Faraday rotation phase shifters. Carrier and unwanted sideband levels of —20 db to —30 db are attainable.

The advantages of using a single-sideband generator instead of a local oscillator lie in the good signal-to-noise ratio obtainable with coherent detection. Many new types of system are now possible with the use of a ferrite single-sideband generator, and expansion in this field seems certain.

CIRCULATORS

Many types of circulator are possible but perhaps the most useful is the four-port circulator indicated in figure 15a. Power entering port 1 emerges from port 2 only, and so on until power entering port 4 emerges from port 1 only. The arrow indicates the direction of power flow. A typical application of the four-port circulator is as a duplexer as shown in figure 15b.

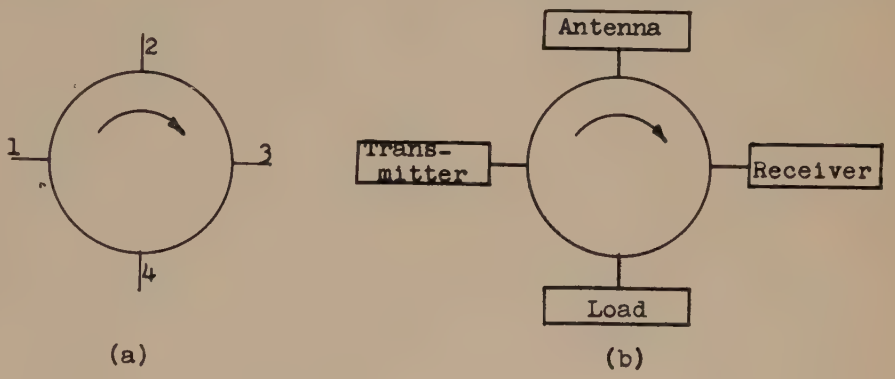


Figure 15 — Circulator

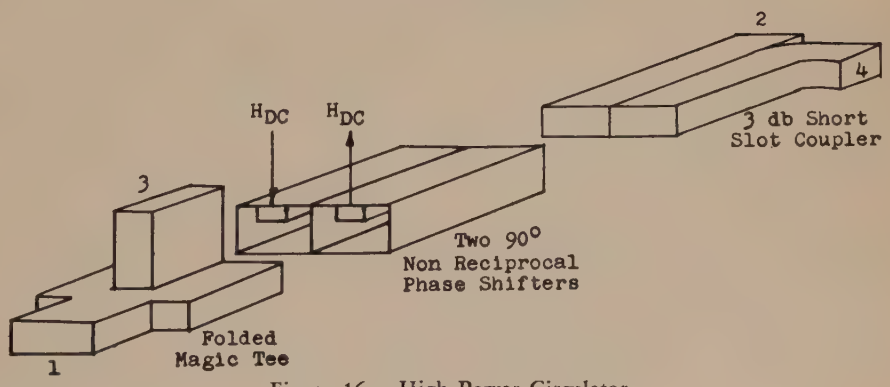


Figure 16 — High Power Circulator

The main advantages of a circulator duplexer are:

(a) Isolation of transmitter from antenna mismatch.

(b) No dead time while TR or ATR tubes recover.

(c) Local oscillator signal coming from receiver is not transmitted but is absorbed in a load.

(d) Duplexing is possible in a CW system.

The main disadvantage of high-power duplexing is that reflections from the antenna are returned directly to the receiver and may cause crystal burnout unless the crystal is protected. The amount of power reflected from any mismatch is given in figure 2. It can be seen that 20 db between transmitter and receiver corresponds to a 1.2 antenna mismatch. However, crystal protection can be afforded by high-speed ferrite switches and, since the power level has been reduced by 20 db. Faraday rotation switches should be usable even in high-power systems.

High-Power Circulators

Figure 16 shows a typical high-power four-port circulator employing two 90° non-reciprocal phase shifters. Such units have been made to cover a 12% frequency band in X-band and give 30 db of isolation. Power rating was about half that of the unperturbed waveguide. Insertion loss is of the order 0.5 db and the VSWR is mainly determined by the magic tee and short slot coupler.

Medium- and Low-Power Circulators

At lower power levels the differential phase-shift isolator is unnecessarily bulky, and a simpler type of circulator is shown in figure 17. In this a wave entering port 1 is rotated 45° and leaves by port 2, while a wave entering port 2 is rotated 45° in the same direction so as to leave by port 3. When a load is to be used in one arm, one of the two mode transducers can be dispensed with if a resistive vane is used to absorb the cross-polarized wave at one end of the rotator section. Again at X-band such a circulator can be built with an overall length of approximately 3 in. and an insertion loss of 0.2 db. With a VSWR specification of 1.3, a bandwidth of 10% would be possible even with this miniature device. Isolation better than 20 db and insertion loss less than 0.4 db would be expected over this range. In such a circulator, at a peak power of 100 kw, non-linearity causes an increase in the insertion loss to 1 db without affecting the isolation. By increasing the length of the unit somewhat it should be possible to reduce such high-power effects considerably.

Although only four-port circulators have been discussed, it is clear that shorting one port will produce a three-port circulator. Further, an n-port circulator may be made by cascading. Loading two adjacent ports of a four-port unit causes it to degenerate into an isolator. Clearly, here is a circuit element for which many uses will be found.

AMPLITUDE MODULATORS AND SWITCHES

Just as ferrites can be used to control the phase of a microwave signal, they can be used to control the amplitude. Apart from rf-power level and frequency range one must now specify the degree of modulation and the rate at which it is to be varied. Another consideration is the type of switching action desired — reciprocal or non-reciprocal. For example, if we use a resonance isolator with a variable magnetic field we can increase the attenuation for a wave traveling from port 1 to port 2 without affecting the attenuation for a wave traveling from port 2 to port 1. Similarly the Faraday rotation isolator or circulator will give non-reciprocal switching action by reversal of the magnetic field.

These non-reciprocal properties can be used to good advantage in certain systems. Consider a klystron which is to be amplitude modulated to a small extent. If a rotational isolator is used, with a coil to supply the necessary field, the klystron will be isolated from the load when the field is adjusted for 45° rotation. If the applied current in the coil is altered, then the insertion loss will alter and amplitude modulation will result while still maintaining some isolating action. The klystron can be switched off if desired by simply reversing the field; the power will then be absorbed by the resistive vane at the output end.

A typical reciprocal amplitude modulator is shown in figure 18. As the field is increased from zero, the plane of polarization is rotated through the angle θ. The incoming wave E may be considered as split into two components: $E\sin\theta$, which is absorbed, $E\cos\theta$, which is transmitted. Thus, if we assume rotation to be proportional to the current I supplying the field, then the transmitted power will be proportional to $\cos^2 kI$.

Amplitude Modulators Using Resonance Phenomena

These modulators can be either reciprocal or non-reciprocal and are

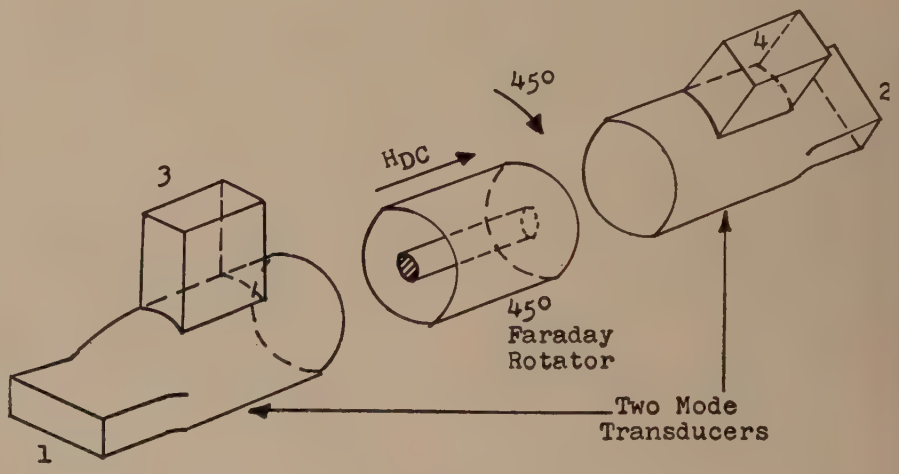


Figure 17 — Four Port Faraday Rotation Circulator

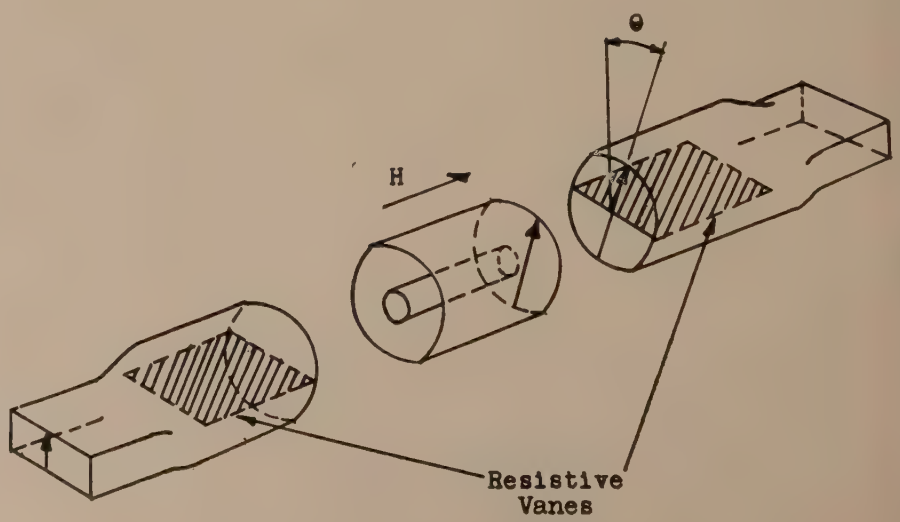


Figure 18 — Amplitude Modulator

usable at high power with suitable design. The main disadvantage of such devices lies in the magnitude of the field required to produce resonance. This implies large electromagnets which require considerable power to drive them and can only be modulated at low rates.

Amplitude Modulators Using Faraday Rotation

These modulators and switches are reciprocal if they use 0° or 90° orientation of input and output and non-reciprocal if 45° between input and output. Like Faraday rotation isolators their use is limited to powers below 100 kw and frequencies above 1,000 mc or so. However, the comparatively small field required enables high-speed switching to be attained without the use of excessive drive power. Figure 19 shows a typical X-band non-reciprocal switch and its specifications. Such switches may be used in pairs (or larger groups) if higher isolations are required.

Figure 19 — An X Band Switch

Model	SXL1
Frequency	10,250-10,500 mc
Power absorbed	5 watts
Isolation	25 db
Insertion	0.5 db
VSWR	1.15
Ext. Driving Power	1 watt
Length	1.7 inches
Weight	15 ozs.

For high-speed switching two factors become important. First, if a rapid rise time is required, the shorted turn presented by the waveguide imposes a limitation; secondly, if the repetition rate is high, the heating caused by hysteresis losses in the ferrite may become excessive.

The shorted turn effect may be overcome by the use of thin-walled waveguide, and in this way rise times of 0.1μs or less can be achieved in a switch giving under 1 db insertion loss to 30 db isolation at X-band. The hysteresis heating effect becomes troublesome when repetition rates exceed 100 kc, although adequate cooling of the ferrite is an advantage and repetition rates of a few megacycles are feasible. By using a ferrite with a small B-H loop in a suitable geometry, by using very small applied fields, or by designing a switch to use a magnetically saturated ferrite, considerably higher repetition frequencies may be possible. Small modulations can be obtained at 10 mc and even higher with driving powers of a few watts.

At present, however, many uses exist for ferrite switches and amplitude modulators for such purposes as klystron modulation and crystal protection. For example, a high-speed switch in conjunction with a ferrite circulator-duplexer should enable the design of radars with much lower minimum range limits than are feasible with conventional gas-tube duplexers. A unit only 4 in. long capable of amplitude-modulating up to 50% has been designed to cover 8.2 to 12.4 kmc; it can be modulated at 10 kc using only a few watts of driving power.

Such devices as these not only extend the possibilities open to designers of new systems, but also provide extra protection and improved performance for existing systems.

OTHER FERRITE DEVICES

So much space has been required for the foregoing discussion of established ferrite devices that the newer developments can be mentioned only briefly. These developments offer great promise for the future.

Klystron tuning and resonant cavity tuning can be accomplished electronically by utilizing the phase and rotation properties of ferrite. Similarly, power dividers and directional couplers can be controlled by their applied magnetic field.

A somewhat more complicated device is known as an isomodulator. This is a combination of isolator and variable-mismatch which is used to frequency-modulate a microwave tube by "pulling" it while at the same time isolating it from load variations.

The non-linear effects observed in ferrites are only just beginning to be exploited. Very efficient (—6 db) harmonic generation at high power has been achieved from 9 to 18 kmc, and mixing at high power is likewise possible. A passive microwave power limiter for such purposes as crystal protection is also now within the realm of possibility. Further, the use of ferrites in microwave amplifiers implies the feasibility of a solid-state oscillator. These last possibilities may prove the most significant use of ferrite since the demonstration of ferromagnetic resonance in ferrites in 1946. In any case, ferrites and ferrite devices have become an essential part of microwave systems and it is doubtful whether any future system will be designed without them.

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THE FORWARD LOOK . . .

in microwave plumbing for systems applications

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THE ADVENT OF microwave ferrites and continued advances in microwave techniques have ushered a whole new era into the use of microwave components in systems design. Devices which heretofore were impossible are now realities; switching speeds, modulation rates in microwave components far exceeding those that were even dreamed of before are now simple and realistic. Because these new devices are essentially controllable by electronic means, the term "electronics" in the microwave component field has now come into its own.

The applications of the new microwave ferrite components to missile guidance radar, tracking antennas, microwave relays, are fabulous. An example is shown in Figure 1.

Microwave ferrites introduce a number of problems because of hysteresis effects in the magnetic materials, variations with temperature, frequency range, etc. The concept of being able to control these shortcomings by means of a closed loop servo system is one that has proved exceedingly valuable in these advanced applications of microwave components.

Production engineering techniques are succeeding now to reduce the cost and to provide for high quantity production of waveguide components. Techniques such as die casting, precision investment, and plaster casting, new constructional techniques for flexible waveguides, jacketing materials, the new epoxies and plastics plus some of the new low loss high temperature dielectric materials open the way to miniaturization and compact structures for missile applications.

An extremely important field in the microwave art is the problem of reducing interference in the now crowded microwave frequency spectrum. Years ago, the microwave region was considered virtually limitless as far as frequency allocation and use was concerned. Today, we face a number of serious problems in frequency allocation, spurious radiation, and harmonic reduction for microwave systems. A number of the techniques which are being developed to reduce spurious radiation and the response of receivers to extraneous signals is described.

High Accuracy Tracking Antennas

Monopulse antennas have become exceptionally popular because of higher tracking speeds and extremely high accuracies which the basic scheme provides. However, in trying to implement these systems into actual hardware, it turns out to be a real problem to provide the exact phase and amplitude balances required in the antenna plumbing to be able to realize the precision potential of large high accuracy tracking antennas. Figure 1 shows a portion of such a system with its associated electronics that yields extremely high orders of tracking accuracy with broadband high powered circuitry. Since this device embodies so many of the new components that are now available for systems use, it would be best to describe this in some detail.

First, the transmitter is connected to either of two antennas through a switched circulator which supplies, in addition to duplexing action, a nonreciprocal switch function so that received signals are returned to the receiver regardless of which antenna is connected.

In the receiver arm of the switched circulator is a built-in noise tube which, during the dead time between magnetron pulses, is fired to monitor constantly the receiver noise figure.

To enhance the dynamic range of the system, a variable microwave ferrite attenuator is also mounted in the receiver circuit to make 100 Db total dynamic range available.

For determining the frequency of operation a servo controlled wavemeter cavity using a remote indicating dial mechanism is used to monitor the frequency of the system. An isolator is included in the line leading to the wavemeter to avoid the wavemeter reaction from affecting the local oscillator power dividing circuits. The local oscillator itself is remotely tunable with a similar type of servo drive and the output level can be adjusted by means of a variable ferrite attenuator similar to the one used for increasing the dynamic receiver range. A dual isolator is included in the local oscillator feed legs which go to other mixers in the system; the phase for which can be controlled by means of ferrite phase shifters in a closed loop servo arrangement to exactly compensate for phase errors in the system. Amplitude errors are corrected for by AGC action in the IF strip and ferrite attenuator.

New techniques for electronic scanning of antenna arrays, using microwave ferrite phase shifters, are being developed. At this writing none has reached the stage where it can be satisfactorily employed in systems application, although from some of the new developments it is apparent that electronic scanning of antennas will soon be a reality.

Beam switching by means of polarization rotation and the use of specially shaped gridded reflectors has been applied in several airborne systems. One of these applications, for commercial airlines weather radar, uses a medium power Faraday rotator to accomplish the switching from horizontal to vertical polarization. With horizontal polarization, the parabolic reflector (solid aluminum) provides a pencil beam which is required for weather radar operation. With vertical polarization, a gridded spoiler (permanently attached to the parabolic spun-aluminum reflector) modifies the beam shape to provide a cosecant-squared pattern which is ideal for ground mapping. This spoiler grid is electrically transparent to horizontally polarize the waves, and thus provides no real degradation of the primary pencil beam pattern.

To accomplish this beam switching, then, no moving parts are required and only 0.6 watt is necessary to energize the polarization rotator. This

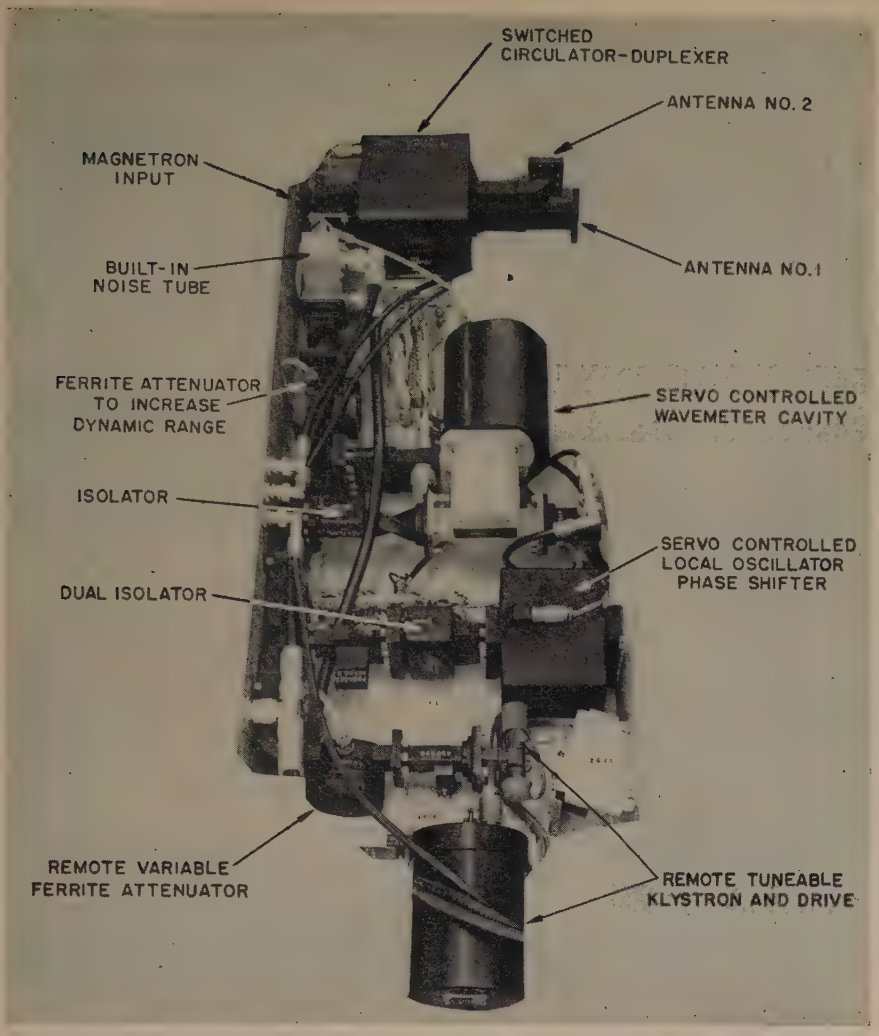

Figure 1 — Complex of microwave plumbing for systems application providing for remote antenna switching, receiver noise figure monitoring and phase correction

rotator has an insertion loss of less than .4 db and will handle up to 70 kw peak power at a pressure corresponding to 25,000 feet altitude. Similar antennas have been constructed at frequencies up to 36 kmc/s for helicopter navigation systems.

Microwave ferrite techniques also make possible polarization diversity, providing instantaneous changeover from linear (vertical or horizontal) to right- or left-hand circular polarization, for rain clutter reduction, etc.

High Speed Microwave Switches

Mechanical switches which heretofore have been used in a number of microwave system applications have been limited to switching speeds nominally in the order of 50 milliseconds. These mechanical devices are cumbersome, expensive and like all mechanical devices are subject to problems if exposed to a military environment, especially in missile borne equipments.

With the advent of microwave ferrite devices, Faraday rotation effect, differential phase shifts, etc., it is now

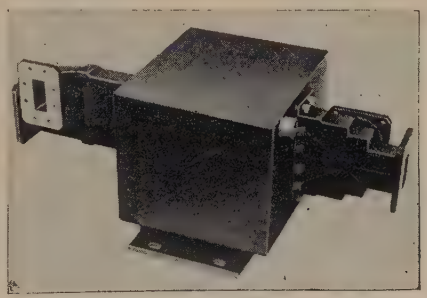

Figure 2 — Microwave switch capable of microsecond switching speeds

possible to accomplish switching at extremely high speeds. With Faraday rotation, switching speeds in the microseconds are commonplace. Figure 2 shows a medium power ferrite switch based on the principle of Faraday rotation.

For narrow-band applications, solid dielectric supported Faraday rotators are used with appropriate orthogonal junctions. For extremely broad-band applications, cruciform or quadruple ridged waveguide structures are used to cover 12% bandwidths.

To achieve extremely high switching speeds, it is necessary to avoid the shortcircuiting effect of the waveguide itself on the magnetic field winding. Several techniques, including the use of extremely thin-wall stainless steel waveguides, provide a solution to this problem.

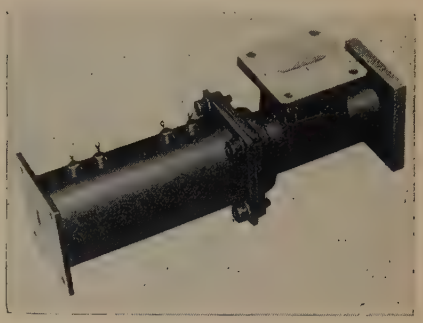

Figure 3 — High powered switched circulator for combined switching and duplexing

Ferrite switches of this type, however, are limited in power handling capacity to something like 50 kw at X-band. To provide high powered switching, devices such as the switched circulator shown in Figure 3 can be used. This basic switch is a phase shift differential circulator arranged with an electromagnet to provide for switching between the two output ports. This very interesting and useful switch is non-reciprocal, that is to say, all reflected signals are returned to a common receiver port, thus, making it possible for a radar to be connected alternately between two antennas and return all the receive signals directly to the receiver without further switching. This also provides inherent magnetron to antenna isolation. Switches of this type have been constructed to handle 250 kw over 12% bands in X-band with under .3 db insertion loss. Switching speeds of this type are nominally in the order of 3 milliseconds. With suitable driver circuitry, it is possible to increase this switching time down to speeds as fast as 50 microseconds, with the expense of higher power driver circuitry.

To realize the high speed switching potentialities of the microwave ferrite devices, electronics again comes into its own and it is here where electronics and microwaves are intimately connected. A number of driver circuits are possible for high speed ferrite switches using both hydrogen thyratrons with pulse forming networks or special line circuitry as well as hard tube modulators and the newer transistors. A combination of permanent magnetic fields with electromag-

netic pulsing circuits makes it possible to provide switches which are permanently connected in one position and may be pulsed into another position for a short interval. This avoids the penalty of constantly providing a steady electromagnetic biasing field with its inherent power consumption. We have only scratched the surface in applying high speed switches to microwave systems.

Electronically Controlled Ferrite Devices

Microwave ferrites, like any other magnetic components, introduce a number of problems. Hysteresis effects, variations of saturation magnetization with temperature, et cetera, all introduce variable performance in ferrite devices. To counteract these effects for precision applications, the use of a closed loop servo system (as shown in Figure 4) is exceedingly valuable for correcting all the variable parameters in the ferrite device itself. The output wave form is monitored by the directional coupler and bolometer mount. A servo amplifier compares it electronically with the input wave form.

If the output wave form deviates from the desired modulating wave form, a correction signal is immediately introduced into the modulator. This makes the output compare exactly with the input wave form so as to take out the effects that would cause errors in the modulated wave form. The accuracy with which this can be done is only limited by the speed of response of this modulating winding and the servo loop gain. From a practical point of view, very precise control of amplitude and phase can be accomplished by this electronic technique of "closing the loop" on the particular circuit element.

Microwave Filter Developments

In the past several years, it has become painfully apparent to microwave systems operators, especially the microwave relay people, that something has to be done about the control of spurious harmonic radiation from radar sets. Front end selectivity also is required on radar sets for friendly interference elimination.

Microwave radar designs have only recently been involved in the application of tuning techniques which are old hat in the low-frequency radio game. Television interference is something that has plagued the radio amateurs since World War II. This interference with microwave relay channels carrying television programs has only begun to be eliminated by filtering techniques in the microwave industry.

Fixed tuned filters in the microwave relay game are common for communication links, microwave relay, etc., but for radar applications, tunability is required. The problem of ganging several cavities and getting these to track over a wide tuning

Figure 5 — Examples of microwave filters: Upper — single knob broadband tunable, Lower — Unit fixed tuned for microwave relay applications

range is not new to receiver designers, but is complicated by several orders of magnitude at microwaves because of the precision required in producing the resonant cavities and the tiny motions involved in tuning these cavities. Single knob multiple cavity filters have been built for several applications and examples of the fixed and tunable filters are shown in Figure 5.

The two-section, gang-tuned preselector filter shown here provides characteristics similar to those of a stand-

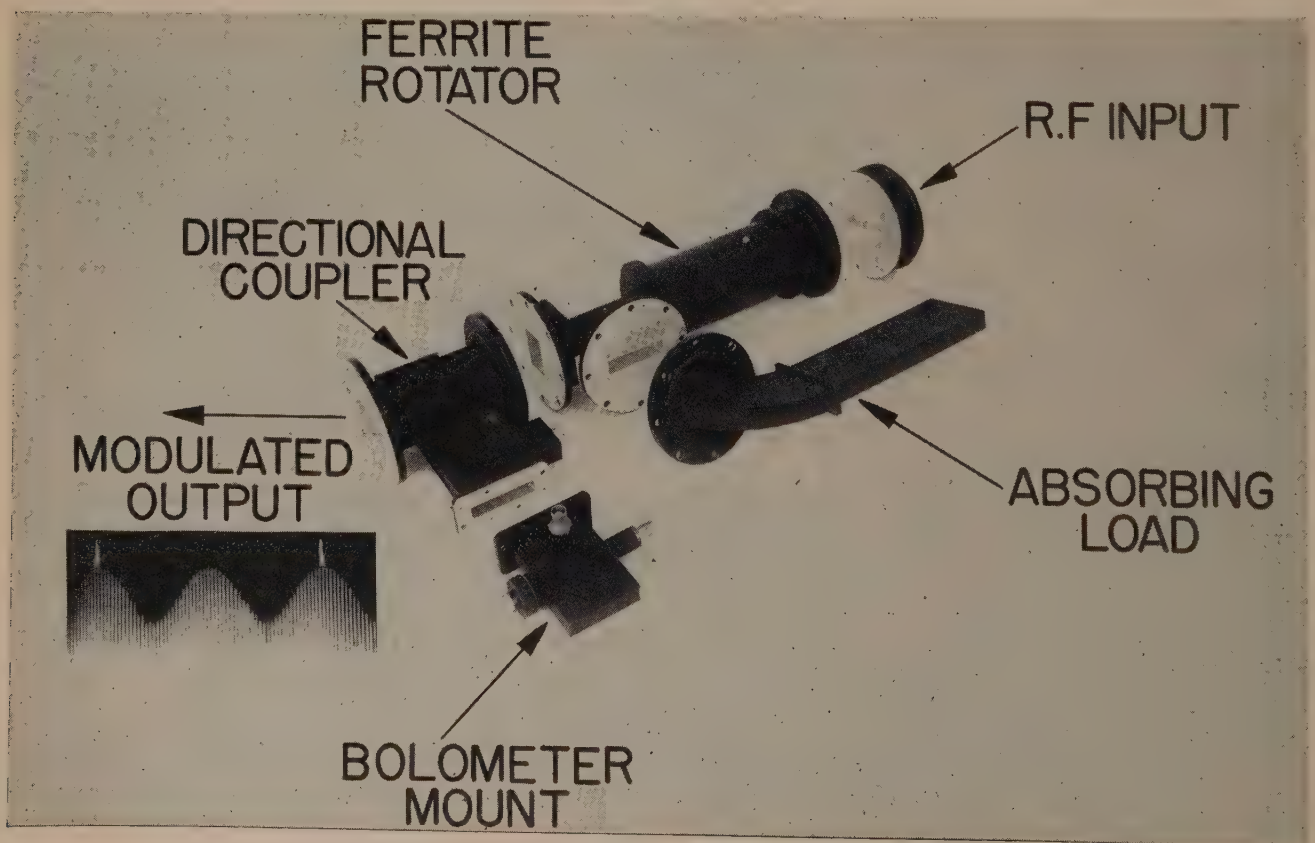

Figure 4 — Servo controlled microwave attenuator using electronic closed loop servo operation

ard four-section model. Each section contains two orthogonal TE_{111} modes, which have the added advantage of a broad tuning range free from crossing or interfering modes. This filter is especially adapted to front-end rejection when high selectivity is required along with minimum size and weight.

The unit illustrated is designed to be continuously tuned over a frequency range of 7500 to 8500 mc/s. Insertion loss does not exceed 2.0 db for a 25 mc/s bandwidth. Rejection obtained with these characteristics is at least 50 db at $F_o \pm 60$ mc/s.

Also shown in Figure 5 is a fixed-tuned filter used in a variety of assemblies for microwave relay applications. A maximally flat (Butterworth) response is obtained with less than 1.0 db insertion loss for a bandwidth of 25 mc/s. At 50 mc/s from F_o the rejection is at least 55 db down. The VSWR of this unit does not exceed 1.20 over its normal pass band.

For broadband radar applications, multisection preselector filters (combined with microwave discriminators and a servo loop) can be used to automatically track the transmitter frequency as the frequency is shifted. For such applications, quarter wave coupled low loss circular TE_{011} modes have been used with as many as 4 cavities ganged to a single shaft which is controlled by the servo motor. The discriminator cavity utilizes an identical section to provide exact tracking between the discriminator frequency determining cavity and the receiver preselector filter. To provide freedom from temperature variations, these cavities are generally constructed of Invar which has a coefficient of expansion of nearly zero. This combination calls for the utmost ingenuity from the microwave component designer, electronic circuit designer and mechanical engineer in order to design a rugged and practical assembly.

Waveguide structures, being essentially high pass structures, will propagate frequencies far above the normal operating frequency range by the very nature of the waveguide medium. This propagation may be both in the fundamental mode and in higher order modes. But the very fact that these harmonics are propagated leads to interference problems which are difficult to eliminate. To provide for a low pass structure in the waveguide, it is necessary to use special techniques to provide for rejection of higher unwanted frequencies. The most common method for doing this is to go into single ridge waveguide by means of a suitable transition and provide a Tchebysheff array of resonant slots cut into the ridge. These slots act as chokes at the harmonic frequencies and prevent the transmission of unwanted harmonic output. Such harmonic filters are required in present-day radars to avoid the problem of interfering with microwave relay systems as was mentioned earlier. Filters of this type have been designed to cover as far as the fourth harmonic of the desired signal frequency without introducing more than 0.5 db insertion loss. With suitable pressurization, such filters can handle substantial amounts of peak power.

Microwave filters differ from conventional filter elements in that distributed constants must be used to make up the filters. Resonant sections of transmission line waveguide, coaxial or stripline, are coupled in any of a wide variety of ways to provide the kind of filter response that is required. For the frequency region from 1,000 to 5,000 mc/s, stripline filters have been widely used for fixed-tuned applications. In the frequency range above 5,000 mc/s, waveguide cavities are necessary to realize high enough "Q's" to be useful. The waveguide cavities are generally sections of waveguide with appropriate iris structures (either direct or quarter wave coupled, depending on band width) and can be tuned by means of capacitive tuning screws. For very high orders of skirt selectivity in microwave filters, it is necessary to go to higher order mode cavities which generally are constructed in round waveguide in a TE_{011} mode.

Flexible Waveguide Trends

Flexible waveguide, in use now for some 16 years, has gone through a whole host of developments. Today, flexible waveguides can be considered essentially equivalent to rigid waveguides in all aspects; high peak power handling capacity, attenuation and mismatch. The newer techniques provide for seamless constructions, extremely good repeated flex life, and for high temperature construction techniques. All-aluminum flex guides are under development with silicon rubber jacketing to meet continuous operating conditions at 500°F.

The use of a circular electric guide with a corrugated transmission line structure has recently proved successful for very long runs of waveguide in both military and commercial applications. We shall, in the future, see a lot of circular waveguides, especially where very long runs of waveguide are involved. Figure 6 shows a corrugated construction designed for use

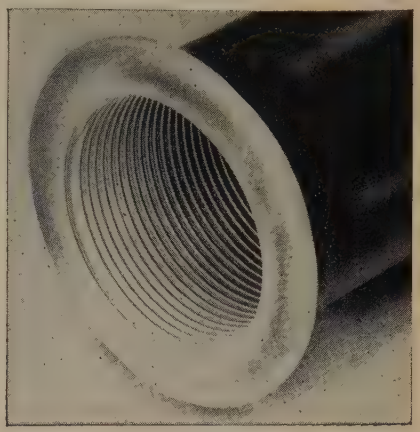

Figure 6 — Flexible waveguide designed for circular electric mode for extremely long waveguide runs at X-band

in a fundamental circular electric TE_{01} wave which has demonstrated attenuation as low as .006 db per foot at X-band making runs of 1000 feet of waveguide practical for specialized applications.

Precision Casting of Microwave Components

New microwave requirements continually challenge the producer of cast components. Tight mechanical tolerances have brought increased emphasis on dimensional control, while proper electrical performance demands improved surface finish and minimum porosity. Complex internal designs make ordinary machining difficult; thus precision casting of microwave components has come into its own in the last few years.

The investment process is particularly useful in casting ferrous metals. This ancient art, combined with the latest in pattern and investment technology, can provide castings of extreme complexity. With modern waxes and plastics, soft metal molds, water soluble wax corings and ingenious wax-welding techniques, parts are made which no other metal-forming process can duplicate.

Plaster casting techniques have been adaptable to the needs of microwave plumbing. Castings made in plaster molds are noted for their uniform hardness and machineability. Slow solidification prevents most internal stresses which cause warpage and distortion, while very smooth surfaces in-

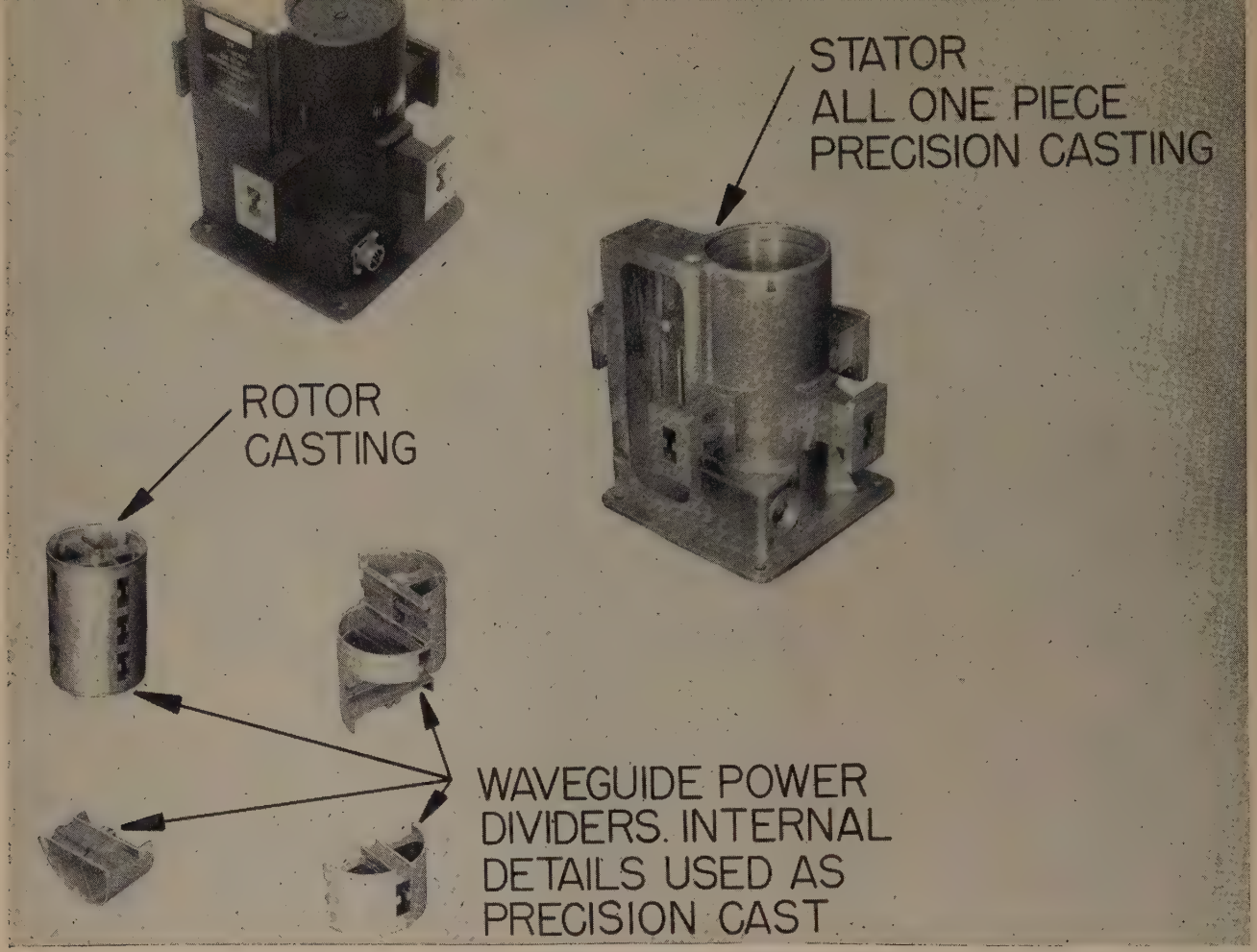

Figure 7 — Precision cast multiple position waveguide switch providing straight through connection, two-way and three-way power split

sure even further dimensional accuracy.

For large scale production, die casting in half-sections which can then be joined by soldering and dip-brazing techniques has also proven to be a practical production technique for microwave plumbing. In general, however, this technique is limited only to large runs where the rather complex and expensive tooling costs can be readily spread over a large quantity of units. Electroforming of precision parts still holds its own for the very complex shapes and very tight dimensional tolerances which even the best in precision casting techniques cannot hold. However, the cost of electroforming is generally prohibitive and with present-day isolators to protect transmitters, receivers, and a number of devices from the effects of undesirable mismatches, there has been some slackening possible in dimensional tolerances for practical waveguide plumbing. It is hoped that this trend will continue.

Some of the sophisticated casting techniques in use today are represented by this compact three-position waveguide switch shown in Figure 7, with cutaway sections of the piston and stator. A plaster mold used for the piston is assembled from nine separate sections; the stator mold requires thirteen. Linear tolerances for both units are $\pm$ .002", while angular tolerances are held to $\pm$ .0° 15′. Cast in Alcoa No. 356 aluminum alloy, the total assembly weighs 5 lbs., 12 ounces.

Special Transmission Lines

With the advent of extended wide band microwave devices for these traveling wave tubes, transmission line components have been required to keep up with the potential needs for this service as well as the requirements for jamming applications.

Double and single ridge waveguides have recently come into very common usage. A whole series of double ridge and single ridge waveguides is now being considered for standardization by the Electronic Industries Association Committee (SQ-11. 1. 3). It is hoped that a series which will suit a wide variety of applications will soon be standardized.

Circular waveguides have recently been standardized for both TE_{11} and TE_{01} operating modes. This is the recently released EIA Standard RS-200.

Strip transmission lines have had a tremendous amount of development since the initial announcements of the basic idea by Federal Telecommunication Laboratories. However, strip transmission line applications have been limited to those applications where space considerations are paramount and some slight performance degradation can be allowed. For the bulk of high performance microwave systems, striplines have now only a small amount of application, but for those applications where space is paramount, stripline techniques offer a very potent tool to the microwave component future.

Surface wave transmission lines, hybrid EH modes in dielectric rods for the millimeter region, image lines, etc., all foretell of possible low loss transmission line structures for the high frequency frontiers.

Microwave tube techniques, microwave ferrite devices, solid state physics coupled with microwave engineering, open up for the future a whole new concept in the microwave plumbing line.

The Types of Microwave Tubes

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A MICROWAVE TUBE is a black box that, under the stimulus of various voltages, does sundry astonishing things. Some of these things are its reason for being. Others are frustrating to the point where the user wonders if tubes are really here to stay, after all. And the fact that the tube designer will earnestly tell the user all the things he is doing wrong, and why this behavior is really what ought to happen anyway, does not help very much.

This condition, taken with the bewildering and rapidly growing list of microwave tubes, many of which are esoterically denoted by alphabetical hieroglyphics, makes it desirable that the average microwave engineer who is not a tube specialist still understands some of the underlying principles of tube operation and classification. It will not answer all his problems, perhaps, to be able to mutter that a BWA is a "distributed interaction, type "O", non-reentrant device using a backward mode of operation with essentially zero energy storage," but at least he can look wise while he is doing it. And it may give him some better feel for what he can expect from a tube or from the tube specialists by way of future devices.

The problem arises because of the peculiar nature of the microwave band itself. It is high enough in frequency so that it is not generally practical to build tubes in which the electrons are moving fast enough to let you ignore transit time. And it is low enough so that you can still use structure to generate a variety of fields you may want, although this structure must usually be built into the tube itself and not simply hung on the outside. Driven by the necessities of the wanted applications and faced with the realities of the physical problem, the tube designers have been inventive in devising structures to make the transit time work for and not against him; but they have not found any single answer. They have found, instead, many, each with its own strengths and weaknesses, each useful for some but not for all purposes. The total this gives is a bewildering list of tube types.

The table that is attached lists many of the common types of tubes (by their popular designations, which are not always identical with the standard terms) and gives their definition in terms of extent and type of interaction, mode of operation, the circuit and beam reentrancy, the energy storage required, and the type of feedback, if any. The meaning and the principal significance of these various classifications are discussed in the following sections.

It will be noted that we have carefully avoided the use of any numbers. We will speak, for example, of high and low power without ever mentioning where the break-over point actually comes. Considering the fact that limits have a way of being broken with new progress, so that to set limits is to invite being given the lie; it is not our purpose to set limits anyway. If power is the principal consideration, and the more power the better, there are certain types of tubes that should be looked at and others that can be safely ignored. From this point of view, limits are set by the state of the art and are not relevant until the user is actually getting down to details. When the user is ready to look at details, he had better consult those who profess to be experts in the art.

We also hasten to add that there are tube types which are not on this list. We have limited the list to those types which have achieved some status as producible and usable items. Others, which are still mainly laboratory items we have ignored, no matter how promising they look. Since this division is a somewhat arbitrary one, we can only present our apologies for the omission of those types which others may think should have been included.

Extent of Interaction

Most microwave tubes fall into two classes, with occasional intermediate types — those with localized interaction between the circuit and the electron beam, and those in which it is extended. If it is localized so that the r-f signal has only a very short time in which to place its mark on the electron, or the electron to jolt the circuit, then the interaction must be intense. This usually means that the r-f voltage must be high compared to the r-f energy involved. Consequently, the circuit impedance or the loaded Q must be high, much higher than the input or output lines. There is energy storage, often to a very substantial extent. Such tubes are almost necessarily very narrow banded. Klystrons are typical of this type of design.

The other type, with extended interaction, allows the r-f voltage to act on the electron, or vice versa, over many periods of the r-f. The best known example is the traveling wave tube (TWT) where the interaction occurs while the electron travels down the whole length of the structure. Since the influence of the circuit on the beam, and vice versa, is accumulated over a relatively long time, the impedance can be low. This allows the effective elimination of energy storage so that the bandwidth can then be very broad. This, however, requires that the electron stay in precisely proper phase with the r-f. In the case of an oscillator, the frequency of oscillation will adjust itself so that this happens and the tube becomes "voltage tunable" over a wide band. If the frequency is to be held accurately, the frequency determining voltage must be closely regulated. In an amplifier where the frequency is fixed by the input signal, then the gain becomes a function of the velocity determining

voltage. In high gain tubes, where the interaction may be very extensive, it is usually necessary to control this voltage very closely.

In the case of M-type tubes, which we will talk about later, the magnetic field is also a velocity determining parameter and must also be controlled, either through control of the current through the electromagnet or by observing proper precautions to avoid change of the permanent magnet.

There are also some tubes, such as some types of magnetrons, in which the interaction is intermediate. These tubes tend to be somewhat sensitive to voltage or pulse shape, but not extremely so.

Feedback

Four types of feedback are used in microwave oscillators:

I. External
II. Circuit Reentrancy
III. Beam Reentrancy
IV. Interactive

The use of external feedback with such tubes as multi-cavity klystrons, planar triodes, etc. is straightforward and, in principle, the same as in lower frequency oscillators.

Circuit reentrancy, such as is used in most magnetrons, uses a circuit that can be described as a slow wave structure that feeds back into itself. Energy, then, may circulate around and around with a small fraction being tapped off by the output as it goes by. Circuit reentrancy is one way of converting a non-energy storing delay line into a high storage device. It, therefore, makes it a narrow band device with relatively intense interaction. As long as the loss per time around is small, the re-entering wave must return in phase with itself. Hence, the total phase delay must be a multiple of 2π. However, it can be any multiple which leads to a spectrum of permissible frequencies. These are, for example, the "modes" of a magnetron.

Beam reentrancy, where the beam may circulate repeatedly through the interaction space, is similar to, and often combined with, circuit reentrancy. It occurs, for example, in a magnetron where only the loss of energy by r-f interaction keeps an electron from circulating around the cathode indefinitely. It serves to increase the strength of the interaction, thus making possible more complete interaction — hence greater tube efficiency than would otherwise be possible without a much longer interaction length. It also limits the bandwidth since the time delay of the modulation on the beam must be such as to cause constructive rather than destructive interference. However, since interaction does occur which limits the storage of information on the beam, this bandwidth limiting effect is much less restrictive than for most conditions of circuit reentrancy. The usable bandwidth is, in consequence, usually reasonably wide.

The interactive type of feedback arises from the mechanism of backward mode operation. Under suitable conditions, a wave propagating in one direction on a delay line creates a field in the interaction space which moves in the opposite direction. This occurs, for example, in a delay line such as an interdigital line, built by the iteration of unit elements whose individual phase delays are negative. To interact with such a circuit in its fundamental mode, the beam is made to travel in the opposite direction as the flow of r-f energy in the circuit. This is the so called "backward wave" type of operation. This type of operation has a feedback mechanism built into it. Modulation on the beam generates an r-f signal that moves back against the beam and re-modulates it nearer to the gun. Since the synchronous condition for proper interaction in such tubes is usually frequency sensitive, such tubes are voltage tunable and may be very widely so.

Interactive feedback is the plague of the designer of a broadband traveling wave amplifier. He will spend much of his time and energy in preventing the tube from finding some frequency at which it can sustain such an oscillation.

Mention should also be made of backward wave amplifiers in which this mode of operation is used in a non-oscillatory manner. Such amplifiers are regenerative. They are useful where narrow band operation that is voltage tunable over a wide band is desired.

Mode of Operation

We have already discussed the mechanism of forward and backward wave operation. Use of a backward wave mode introduces what we have called "interactive feedback." Hence, tubes using it are either oscillators or regenerative amplifiers. Furthermore, while not theoretically required, the backward wave structures used are generally "dispersive," *i.e.,* the phase velocity of the backward space harmonic is a function of the frequency. Hence, the condition of synchronism — that the beam must move at approximately the same speed as the wave with which it is to interact — means that a beam will interact effectively only at a specific frequency. If the tube is an oscillator, it is voltage tunable. If an amplifier, then, at a given voltage, it will function only over a narrow range of frequencies. The center of this pass-band will then be voltage tunable.

Forward wave interaction has of itself no built-in feedback mechanism. (Although reflections, higher modes, and other complications are liable to create feedback loops in any actual tube which are often the bane of the tube designer.) Feedback, if the tube is an oscillator, must be provided by one of the other possible mechanisms. Forward wave structures may or may not be dispersive. The phase velocity of the forward space harmonic being used may, or may not be, a function of the frequency. If it is not, then the tube is broad banded over the range of frequency for which it is not. If it is dispersive, then the tube will be voltage tunable with a limited pass-band at any given voltage.

In magnetrons, we also speak of π-mode operation. This concept applies to other tubes as well, such as some types of klystrons. In π-mode operation, there is exact phase reversal between successive elements of the anode. The phase delay across the unit filter sections of which the anode is built is π radians, which may be taken as either plus or minus. The field on such a line, therefore, may be looked at as either forward or backward, or as a standing wave pattern formed by combining forward and backward waves. π-mode operation occurs at the cut-off frequency of the line. It occurs, therefore, at a single frequency; although in some tubes, the anode can be adjusted mechanically, or otherwise, to achieve tunability.

A further word may be in order here about the classification of delay structures into forward and backward types. An electron "sees" the field on a delay structure only intermittently as it passes from one section to the next. This has a sort of stroboscopic effect so that the field the electron

"sees" can be given only as the Fourier sum of a theoretically infinite number of waves all at the same frequency, but each moving at its own speed. These are improperly called "modes," and properly called the "space harmonics" of the field. Some of these will be forward and some backward — *i.e.* either moving in the same direction as or against the flow of energy. One of these will be faster than all the others. This is called the "fundamental" space harmonic and as it is forward or backward, so is the line.

This behavior can be readily seen from filter theory. All practical delay lines can be looked at, at least approximately, as constructed by the series connection of a large number of identical sections. Across any such section there is a phase delay θ. To this can be added or subtracted any multiple of 2π so that we can set

$$\theta_n = \theta_o + 2_n\pi$$

where θ_o is the smallest of these, so that

$$-\pi \leqslant \theta_o \leqslant \pi$$

(for π-mode operation, $\theta_o = \pm\pi$ and there is ambiguity as cited above).

All of these $\theta\pi$'s are angles, each of which may properly be considered as the phase delay of the section. If d is the physical length of a unit, then each angle has a velocity v_n associated with it

$$v_n = d/t_n = d\omega/\theta_n = d\omega/\theta_o + 2_n\pi$$

where t_n is the time delay associated with a phase delay of θ_n.

Since n may be any integer, positive or negative, there are an infinite number of velocities, some of which are positive (forward harmonics) and some negative (backward harmonics). v_o, when $n = o$, has the largest magnitude and it is positive or negative as θ_o is positive or negative.

This harmonic, whose speed is larger in magnitude than that of any other harmonic of the same frequency, is the "fundamental" harmonic. Most tubes are designed for interaction with this harmonic only. As the sign of the velocity of this harmonic is positive or negative — as it moves in direction of or against the flow of r-f energy — so is the line designated as "forward" or "backward."

Type of Interaction

There are two types of interaction commonly used in microwave tubes which are often designated as types "O" and "M". The distinction lies in the d-c fields that enter actively into the process. Type "O" is the simplest. There are no applied d-c fields involved. The electrons, after their injection by the gun into the interaction space, coast free, subject only to space charge forces and to the r-f field itself. There often is, in addition, an axial magnetic field whose function is to hold the beam together against the dispersive space charge force. This, however, takes no part in the interaction dynamics and is therefore not counted for this purpose.

"M" type interaction is used in what are collectively called "crossed field" tubes. A d-c electric field is imposed across the beam. Left to itself, it would promptly pull the beam into the anode. However, a d-c magnetic field is also imposed at right angles to the beam and to the field. A moving electron is an element of current. Since this is moving across the magnetic field, there is a magnetic force on it which is arranged to act against the electric force. The magnetic force is proportional to the speed of the electron, which is proportional to the square root of the voltage difference between its location and the cathode. Hence, as the electron gets nearer to the anode in free fall (*i.e.* without r-f interaction), the magnetic force gets stronger. There is, then, some voltage level at which an electron is moving just fast enough so that the magnetic force can just balance the electric force. Such an electron, if started in the right direction will move uniformly along the equipotential, at least as long as the equipotential does not bend too rapidly. Any other electron will oscillate about this path.

The significance of "M" type interaction is that the *average* speed of an electron along any path it may take in the field is just the ratio of the electric to magnetic fields. (Neglecting space charge and some other second order effects, but very nearly true in all cases of interest.) As the electron delivers energy to the r-f field, so that the field attempts to slow it down, the electron moves up toward the anode so as to recover fully the kinetic energy corresponding to this speed. Interaction occurs at the expense of the potential rather than the kinetic energy. Hence, the electron remains in synchronism and, therefore, can continue to deliver its energy effectively until it finally falls into the anode.

In an "O" type tube, on the other hand, the electrons deliver energy at the expense of their speed. There is danger, if too much of their energy is removed, that they will no longer maintain proper phase relation with the r-f on the circuit and will "fall out of synchronism." They are, therefore, limited as to their efficiency.

The other side to this coin is the fact that "M" type tubes seem generally to be noisy. Whether this is inherent in the "M" type beam or simply the result of our ignorance of how to build quiet tubes is not known. We suspect, however, that such beams are inherently noisy.

This seems plausible as we consider that an electron in crossed fields moves under strongly opposing forces. The possibility of turbulence arising under these conditions would appear to be good. In any case, it does seem to be the observed fact that "M" type tubes do tend to be rather noisy.

Hence "M" type interaction is most commonly used in power tubes where efficiency is most important and where noise is of least importance.

There is one additional factor that is involved here. As we push an "M" type tube toward exceedingly high power levels, the electric field strength must also be pushed up. There comes a point beyond which it becomes difficult to prevent internal break-down. In "O" type tubes, on the other hand, the high voltage exists between the gun and the interaction section, and, aside from the practical difficulties of it, there is no reason why this cannot be made as long as desired. There is, in other words, a separation of functions that makes an "O" type tube possible long after an "M" type seems to become impractical. For the very highest powers, therefore, the tubes used are often type "O", such as klystrons, TWT's, etc.

Conclusions

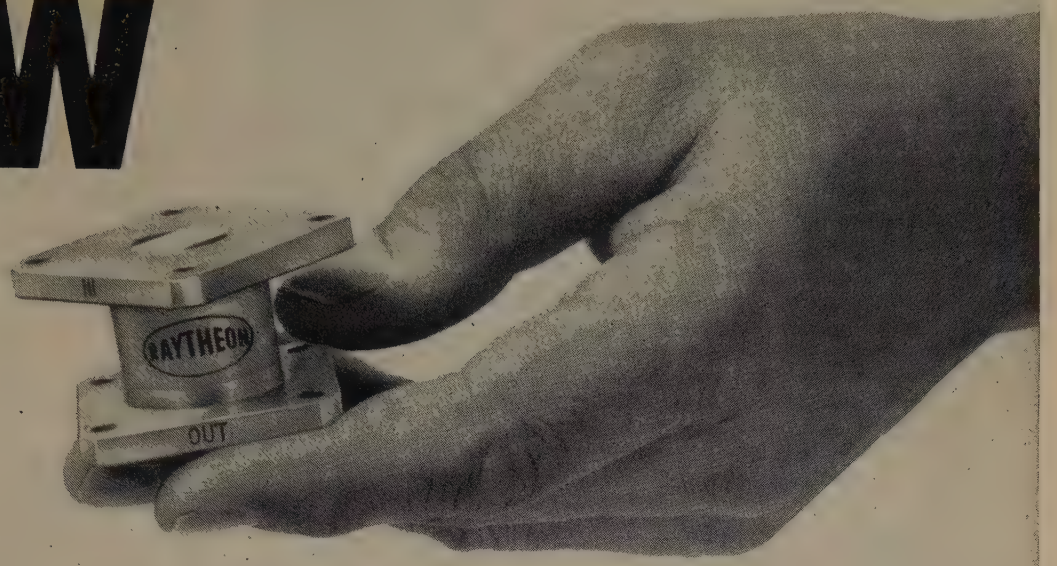
We repeat that this list does not include all possible types of tubes which may become important in the future. Neither have we discussed all the implications of the various features we have used for classifying the tubes. It is our hope, however, that we have included those tubes which are of most widespread interest, and that we have shown why certain of their basic characteristics are implied by the very definition of the type. It is also our hope that the understanding of these relations will prove useful and suggestive to those who have to use these tubes.

THE TYPES OF MICROWAVE TUBES

AMPLIFERS	Interaction		Operation Mode of	Reentrancy		Energy Storage	Feedback	Major Use
	Extent	Type		Circuit	Beam			
TWT (Traveling-Wave Tube)	extended	"O"	forward	no	no	no	no	Broad band amplifier
Klystron, multicavity	local	"O"	(1)	no	no	no	no	Power amplifier
"Amplitron" (3)	intermediate	"M"	backward	no	yes	no	interactive	Power amplifier — locked oscillator
BWA (Backward wave amplifier)	extended	"O"	backward	no	no	no	interactive	Regenerative, voltage tuned amplifier
OSCILLATORS								
Magnetron	intermediate	"M"	π	yes	yes	high	interactive and Reentrant	mechanically tunable
Klystron, multicavity	local	"O"	(1)	no	no	high	external	narrow band voltage tunable
Klystron, reflex	local	"O"	(1)	yes	no(2)	high	reentrant	narrow band voltage tunable, low level
BWM (backward wave magnetron)	extended	"M"	backward	no	no	no	interactive	wide band voltage tunable, high power
"Stabilotron" (3)	intermediate	"M"	backward	no	yes	high	external	mechanically tunable
BWO (backward wave oscillator)	extended	"O"	backward	no	no	no	interactive	wide band voltage tunable, low level
VTM (voltage tunable magnetron)	intermediate	"M"	(?)	yes	yes	no	reentrant	wide band voltage tunable (magnetron loaded to minimize energy storage and current independent of voltage.)

Note: (1) Not significant (2) Beam not re-used (3) Trade Mark by Raytheon Mfg. Co.

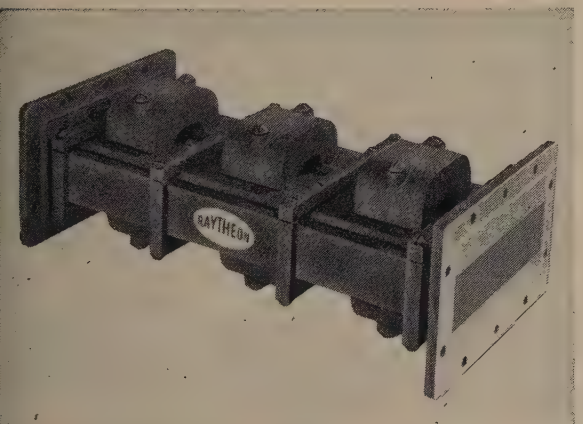
NEW



MINIATURIZED MICROWAVE ISOLATORS such as this new Raytheon X band unit weigh as little as 6 ozs.

MICROWAVE FERRITE ISOLATORS

—New designs now available for several bands



NEW HIGH POWER L-BAND ISOLATOR, first of its kind, typifies Raytheon leadership in microwave ferrite materials and devices.

You'll want to learn more about Raytheon's new full line of microwave ferrite load isolators as well as other devices now available commercially for the first time. Included in the line is a completely new L-band isolator, the first of its kind ever built. There are also units for S, C, X, K_E, and K_U bands.

RAYTHEON'S TYPE R-151 FERRITE MATERIAL is available for Faraday rotation devices in X and K band frequencies and for resonant-type isolators in S through K bands. Other compositions are available for various applications.

WRITE TODAY for technical data sheets on standard Raytheon microwave ferrite devices and material. Please state your specific requirements for more complete data. Write to R. M. Moschella, at address below.

RAYTHEON

Excellence in Electronics

RAYTHEON MANUFACTURING COMPANY

SPECIAL MICROWAVE DEVICE GROUP
RIVER BUILDING NO. 2, WALTHAM 54, MASS.
SEE OUR EXHIBIT AT WESCON, BOOTH 610-611

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Dave Ingalls — Vice President
Litton Industries, Inc.

AIRTRON-LITTON MERGER

Litton Industries, Inc. of Beverly Hills, Calif. and Airtron, Inc. of Linden, N.J., will merge, effective August 1, it was revealed today by David Ingalls, President of Airtron.

The companies, manufacturers of electronic components, primarily in missile work and space research, signed an agreement, subject to approval by certain government agencies.

The firm will be known as Airtron, Inc., Division of Litton Industries, Inc.

Mr. Ingalls remains as President of this Division.

Mr. Ingalls said that recent advancement in the fields of science and management are making it necessary to combine the resources of many large corporations in order to get the brains and manpower together.

Airtron, if it is going to engage in large-scale operation, must have more top level planning and financing, he said.

Airtron presently has five plants located in Linden and one in Cambridge, Mass. Litton is made up of a group of companies employing 8,300 people in 12 states.

One of these companies is located in San Carlos, California and makes magnetrons and klystrons. The Triad Transformer Company located in Venice, California makes a complete line of transformers. The Maryland Division of Litton Industries does extensive work in airborne and land base navigation equipment. The Monroe Calculating Machine Company, which is located in Orange, New Jersey, makes office machines and equipment.

In addition, Litton Industries maintains an engineering group in Beverly Hills, California and has major contracts for an inertial-guidance system. They are also engaged in space research and building digital computers for current aircraft and missile production.

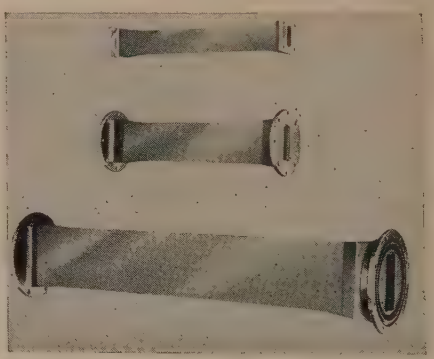
Airtron will have added a new division to be located in Culver City, California. This group is now operating as a part of Litton Industries Components Division, and is in the field of ferrites. They will complement the work of the Cambridge, Massachusetts division.

Premier Instrument Corporation Moves to Port Chester

Leonard Kardon, president of the Premier Instrument Corporation of New York City, has announced the moving of its present facility to make way for the Washington Square Housing Project.

The move to take place July 1, 1958 to a new plant, designed and constructed expressly for the manufacture of microwave assemblies and components.

Airtron Offers Flexible Waveguides With Silicone Rubber Jackets

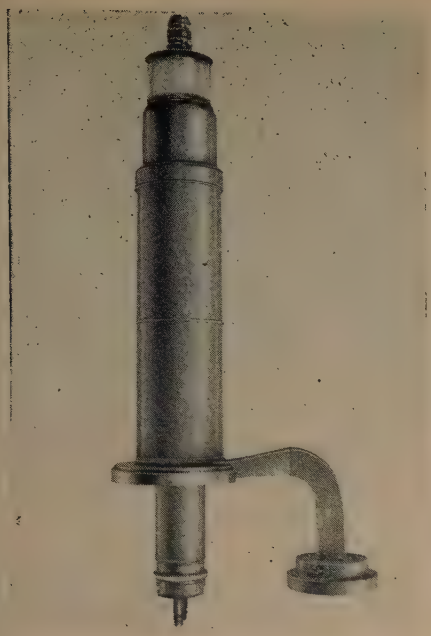


Low and high temperature resistant silicone rubber molded Flexaguide has been made available by Airtron, Inc., Linden, N.J.

Designed to operate over a temperature range of —100°F to plus 300°F, higher for short periods, the silicone rubber jacketed Flexaguide assemblies retain complete flexibility, with a minimum bending radius identical to that of neoprene molded flexible waveguides.

Available in all waveguide sizes from WR-284 to WR-28, the new assemblies may be obtained with standard military type or RETMA type, brass or aluminum flanges in all combinations for both pressurized and non-pressurized applications.

CIRCLE READER SERVICE CARD 102



New High Power TWT Amplifier By Varian

Varian Associates' new VA-125 a one megawatt 2.7-3.0 Kc TWT amplifier for modern radar.

The VA-125 gives systems engineers greater freedom in radar design. A broadband, high gain, liquid cooled TWT pulse amplifier, the VA-125 is intended to cover a large portion of the S-band without tuning and is for use in coherent high power radar applications. With additional drive power, it can be used interchangeably with the VA-87 Amplifier Klystron in systems that call for very broad band operation.

The X-ray shielding is provided as an integral part of the VA-125 and its accompanying VA-1503B focusing electromagnet. The VA-125 has a useful bandwidth of 375 Mc and a power gain of 28 db. Pulse beam voltage is 110 kV and pulse beam current, 60A. The VA-125 can be operated at a duty cycle of .002.

CIRCLE READER SERVICE CARD 103

Characteristics Tabulation of Microwave Tubes

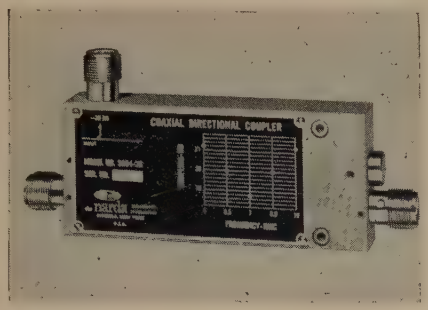
Now available for purchase by single edition or semiannual subscription, this Microwave Tube Tabulation includes both American and foreign types, in order of frequency and power, with a cross-index by type number indicating all manufacturers of each type. Request further details from Derivation and Tabulation Associates, Inc., 67 Lawrence Ave., West Orange, N.J.

CIRCLE READER SERVICE CARD 104

New C to X Band Coaxial Couplers Announced by Narda

A new broad band series of coaxial couplers covering a 2½ to 1 frequency range with flat coupling and high directivity from 4,000 to 10,000 mc has been introduced by the Narda Microwave Corporation, Mineola, N.Y.

A unique feature incorporated into each new coupler is a name plate which includes a chart providing calibration to 0.2 db accuracy at *five* frequencies.



To insure the high directivity characteristics of these couplers, the secondary arm termination is completely built-in.

Models are available for 10, 20, and 30 db coupling, all with Series N, female connectors and a 1.2 primary line and 1.3 secondary line VSWR.

CIRCLE READER SERVICE CARD 105

Battery-Operated VSWR Amplifier

A new transistorized VSWR Amplifier, which is battery-operated and therefore completely independent of line voltage deviations, has been developed by the Narda Microwave Corporation, Mineola, New York.

The new Narda VSWR Amplifier offers other advantages as well: an unusual feature provides full sensitivity over the expanded VSWR scale and eliminates the need for switching attenuation range when going from normal to expanded scale. The noise level (less than .02 microvolts equivalent) and amplifier gain remain the same in the expanded position. Sensitivity is 0.1 microvolts at 200 ohms, over the full scale.

Batteries are of the mercury type, with 600 hours operating life guarantee; two years shelf life. The Amplifier covers the frequency of 1,000 cps 1%, with plug-in frequency networks available for 315-3000 cps; offers a 25-30 cps bandwidth, and 70 db range (60 db in 10 db steps, 10 db continuous).

CIRCLE READER SERVICE CARD 106

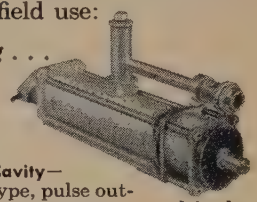
NOW...ANY MICROWAVE COMPONENT CAN BE BUILT AND ENGINEERED TO YOUR PARTICULAR APPLICATION

Regardless of complexity, design or tolerance problems—you can get UHF or microwave components that are job-engineered to your application. All units are delivered, *electrically tested and proven*, ready for immediate operation.

Components can be built from your prints or can be designed and built to integrate with the application. Close and confidential coordination is maintained from drawing board stage to installation.

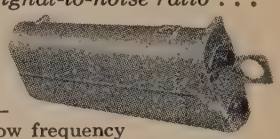
Range of assemblies is practically unlimited—from dc. to over 40,000 mc., military or industrial. Typical examples are these components, delivered ready for field use:

Telemetering . . .



Tuneable S-Band Transmitter Cavity— re-entrant type, pulse output 150 w., operates at extreme altitudes and under extreme conditions of temperature, humidity and salt spray.

Improving signal-to-noise ratio . . . selectivity...



Tuneable UHF Pre-Selector— relatively low frequency coaxial resonator with very low insertion loss, extreme selectivity and very high signal-to-noise ratio. Especially adapted to use in aircraft or in crowded communication bands.

Calibrating...designing S-Band components...

S-Band Signal Generator Cavity— re-entrant type, complete with thermistor mount and calibrated variable attenuator. Frequency range 2700 to 3400 mc.

CUSTOM-ENGINEERED MICROWAVE PARTS

Get the facts on our complete design, engineering and mechanical fabrication facilities. Have us quote on your needs—cavities, mixers, duplexers, multipliers, rotary joints, twists, bends and other components or assemblies.

Contact us today. Request catalog.

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9311 West 47th St., Brookfield, Ill.
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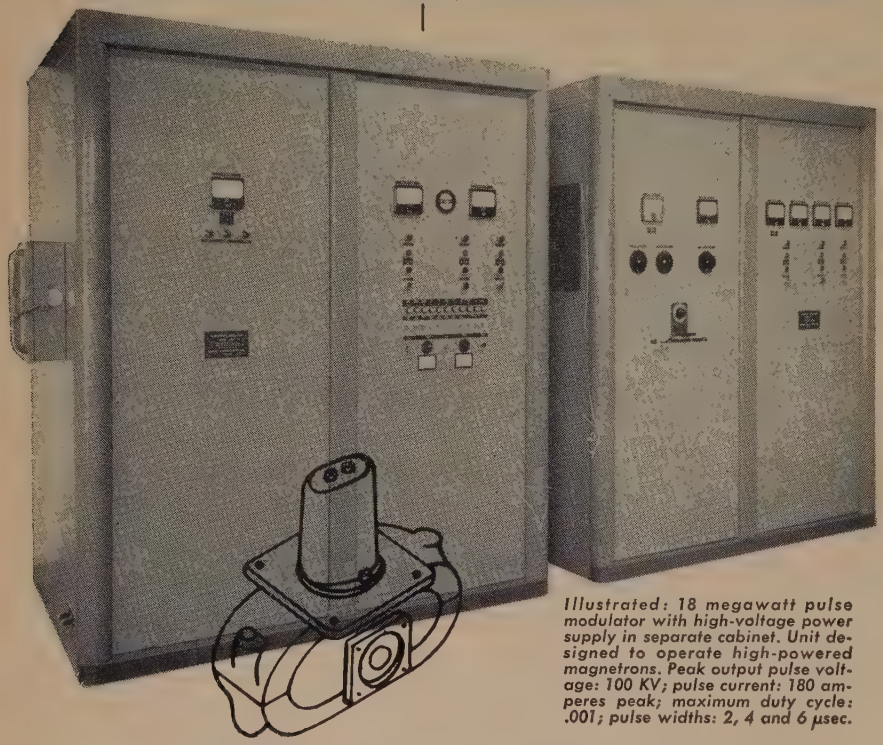
CIRCLE READER SERVICE CARD 9

Testing MAGNETRONS KLYSTRONS CARCINOTRONS

● OTHER MICROWAVE TUBES, COMPONENTS OR SYSTEMS?



Illustrated: 18 megawatt pulse modulator with high-voltage power supply in separate cabinet. Unit designed to operate high-powered magnetrons. Peak output pulse voltage: 100 KV; pulse current: 180 amperes peak; maximum duty cycle: .001; pulse widths: 2, 4 and 6 μsec.

Come to Manson for the widest selection of standard *Pulse Modulators* and *High-Voltage Power Supplies* covering all useful power levels. From kilowatts to tens of megawatts, Manson has precision-engineered designs for operation and test of magnetrons, klystrons, traveling wave tubes, backward wave oscillators, lighthouse tubes, pulse transformers, waveguide components and related devices. The wide range of standard models is readily adaptable to meet individual specifications.

HIGH POWER PULSE MODULATORS:

Hard- and soft-tube types from 16 kw. to 30 megawatts peak power output, and higher. Average output powers as high as 60 kilowatts. Typical operating features include: continuously adjustable voltage control; discrete or variable pulse widths; internally- and externally-controllable repetition frequencies; auxiliary synchronized outputs; pulse-shape monitoring circuits; and interlocking and overload protection.

HIGH VOLTAGE POWER SUPPLIES:

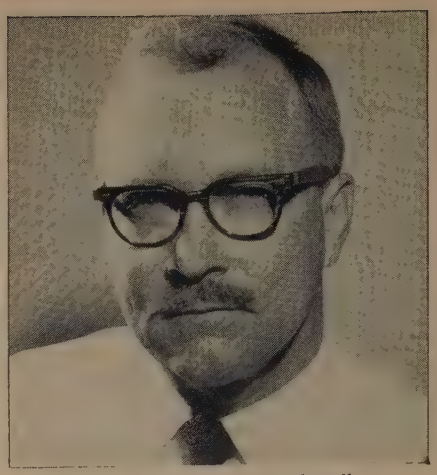
High-voltage DC and AC types, single- or multiple-output, regulations and stabilities to 0.01%. Standard and custom designs to satisfy your specific tube testing or production problems: highly-regulated supplies uniquely suited for TWT test and operation; unregulated high-power supplies for systems testing; and complete power sources for controlling all aspects of tube production.

Write today for complete details on our full line of high-power pulse-test equipment and high-voltage power supplies, including applications and performance data.

MANSON LABORATORIES, INC.

207 GREENWICH AVE. STAMFORD, CONN.

Manson offers to engineers and technicians a rewarding present and attractive future in Connecticut.



Burt Bittner — First Subscriber

Years ago, when the writer was an eager "ham" and had just put his wavering 30-watt c-w signal upon the 20-meter band, and listened hopefully for some response in the earphones of his twotube regenerative receiver, days went by with nothing doing. Then, one fine morning, the postman brought a card from an SWL in Chicago. We have never forgotten that man.

Similarly, we at microwave journal will always remember with affection and gratitude the name of Burt Bittner. His was the first reply card to arrive at our offices in answer to our first pre-publication promotional piece.

JWH

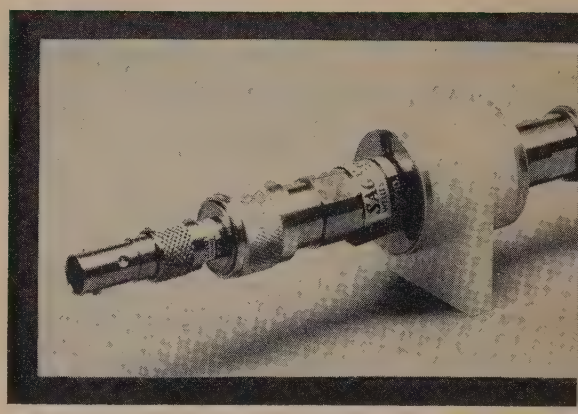
BURT J. BITTNER, manager of the Nuclear Instrumentation Division of Gulton Industries, Inc. 1948 to 1956, R.F. and Lambda Division Supervisor engaged in AEC weapons test components design at Sandia Corporation. Supervised Radar Terrain Return Program at the Corporation for five years. Fire Control Radar Antenna Design Engineer with Submarine Signal Co., 1946 to 1948. Countermeasures Radar Officer of Naval Research Laboratory and other military activity. Author of numerous publications and a Scientific Member of the Solar Energy Association. Senior Member of the IRE. Special achievements include design or supervision of design of 83 types of Telemetry Antennas of which many types are in current use in Atomic Energy Programs. Other achievements include the Mk44 Organ Pipe Scanner Antenna, the Spherical "Bird-Cage" Antenna that allows 360° scan without movement of the reflector, and the APOTA Telemetry Automatic Tracking Antenna. He has held many IRE posts including chairman of the Albuquerque-Los Alamos IRE section.

Microwave . . .

Engineering Specialists

Product Design

Custom Development



On the right is shown the Sage 505 Isolator and 101 BDJ Crystal Holder. This combination detects from 50 mc to 11,000 mc with at least —40 DBM sensitivity (10 mc video bw) while suppressing noise below 10 mc.

New products include the Sage Cobrid, wide band noise isolator, tunable filters and slotted lines.

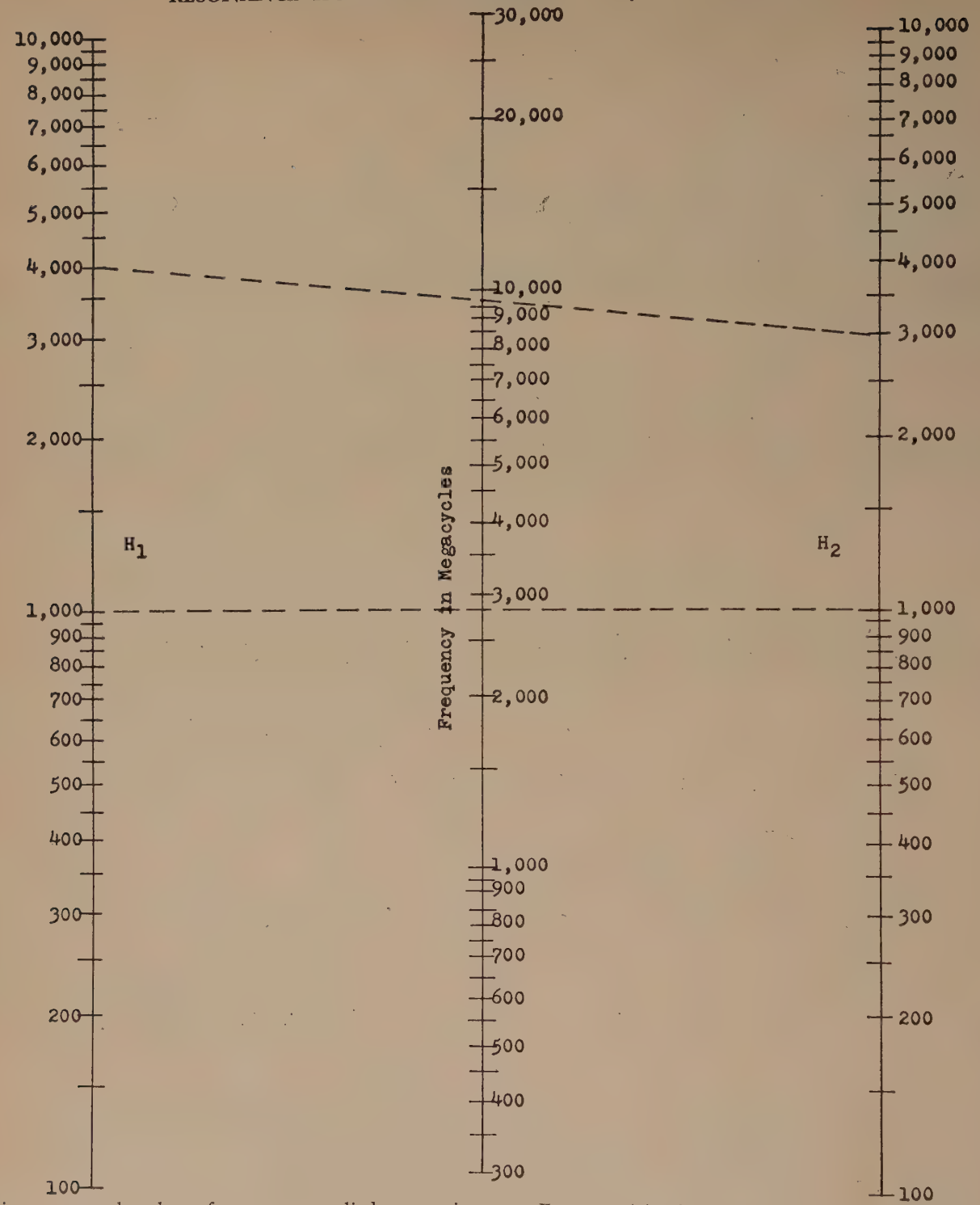
We invite your inquiry on special microwave problems.

CIRCLE READER SERVICE CARD 11

SAGE laboratories, inc.

159 LINDEN STREET WELLESLEY 81, MASS.

RESONANCE ISOLATOR NOMOGRAPH — By David Andrews



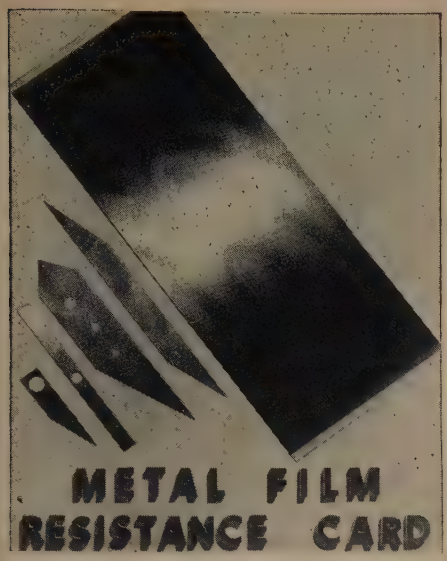
This nomograph relates frequency, applied magnetic field, and saturation moment as given by Kittel for three different isolator configurations. The three cases are (1) a flat slab against the broad wall of the waveguide, (2) a flat slab with its narrowest dimension against a broad wall of the waveguide, and (3) a slab with square cross-section. The same nomograph may be used for all cases with slight modification.

For case (1), the H-plane isolator: On the H_1 and H_2 scales note the value of the applied magnetic field minus the saturation moment. The line joining these points will intersect the frequency line at the resonant frequency. The lower dotted line drawn on the nomograph illustrates a resonant frequency of about 2800 mc for an applied field 1000 gausses higher than the saturation moment.

For case (2), the E-plane isolator: On H_2 select the value of the applied magnetic field and on H_1 note the sum of this field plus the saturation moment. The intersection on the frequency line is the resonant frequency. The upper dotted line shows an applied field of 3000 gausses, a moment of 1000, and a resonant frequency about 9600 mc.

For case (3), the square cross-section: On H_1 note the field and on H_2 note the difference of this field minus half the moment. The intersection is the frequency. The upper dotted line could indicate an applied field of 4000, a moment of 2000, and again a resonant frequency of 9600 mc.

In all cases γ is assumed to be 2.8.



METAL FILM RESISTANCE CARD

Filmohm Metal Film Resistance Card is a new highly stable microwave attenuator material. The base is a fine weave glass cloth impregnated with high temperature thermosetting resin which meets MIL-P-18177. Resistance material is a thin film of pure metals approximately 50 millionths of an inch thick, uniformly deposited on one surface of the plastic. A protective coating is provided over the metal film.

No special machining techniques are required. Filmohm Resistance Cards can be punched drilled, sheared, machined, and sanded with normal care to avoid scratching the film surface. Maximum surface temperature should be limited to 130 deg. C.

Standard resistance cards are 5 x 12 inches, and .025, .032, or .062 thick. Resistivity range is 25 to 750 ohms per square. Standard values from stock include 50, 100, 125, 150, 180, 200, 300, 377, 400, and 500 ohms per square.

CIRCLE READER SERVICE CARD 107

ANTENNA INSTRUMENTATION PACT TO SCIENTIFIC-ATLANTA

Atlanta, Georgia, June 1, 1958—Scientific-Atlanta, Incorporated, 2162 Piedmont Road, N.E., Atlanta 9, Georgia, has received a contract from Wright-Patterson Air Force Base for developing a high speed antenna pattern recording system, it was learned this week.

An official of the firm's special products division stated that the award was for approximately $175,000 with delivery in about fifteen months.

FOR YOUR PARABOLIC REFLECTORS

get maximum accuracy at minimum unit cost with Torngren's exclusive MECATORN spinning process.

Reflectors spun by the hydraulic, semi-automatic MECATORN process are stronger and more uniform. They insure maximum gain and uniform phase front. Surface irregularities are kept to a minimum. Accuracy is maintained to tolerances as low as 1/64th of a wavelength. Template inspection guarantees quality control.
Diameter range: from 6 inches to 12 feet.

C. W. TORNGREN COMPANY, INC.

236 Pearl Street
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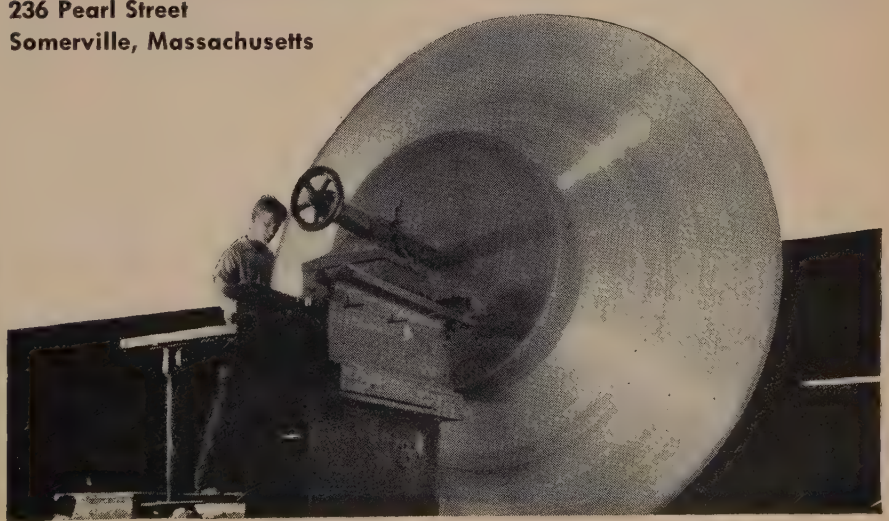
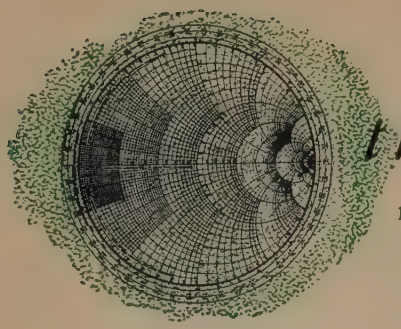




the microwave journal

160 WARREN STREET, BOSTON 19, MASSACHUSETTS

Dear Reader:

"the microwave journal" is a new publication aimed for those people working at microwave frequencies in the fields of antennas and propagation, electron and solid state devices, systems and components manufacturers. It is primarily a technical journal but is also intended to be informative and instructive to the sales, purchasing, production and executive groups.

The main purpose of this letter is to solicit papers, new products, tables, etc. If you feel that you have any material which would fall into these categories, we would appreciate an opportunity to consider its inclusion in one of our early issues.

Articles of engineering merit to the microwave industry are requested. We welcome and encourage papers of a tutorial nature. The paper should contain at least 4,000 words. Graphs and illustrations should be original drawings. At least $50.00 will be paid to the author if accepted. We will be happy to supply more detailed information and specifications upon inquiry to the editor.

For useful graphs and tables, which are accepted, "the microwave journal" will pay $10.00. The final decision of which graph will be used shall be up to the editors, since there is some chance of duplication. They will be handled on a first-come first-served basis.

In addition to the technical articles we will be glad to receive news items, novel ideas, new products, news of people and companies.

Our present plans call for the next issue to appear in September. From then on the magazine will be published on a monthly basis.

The "microwave journal" is mailed free of charge to all qualified persons working at microwave frequencies, in research, development, purchasing and sales. Our mailing list is over 12,000 at this time.

I would appreciate it if you would call the journal to the attention of anyone whom you feel would be interested in this publication.

If you have any questions, please feel free to call us at any time.

Kindly address all material to "the microwave journal," 160 Warren Street, Boston 19, Massachusetts.

Sincerely,

Theodore S. Saad

Theodore S. Saad
Editor

BOULDER CONFERENCE

A Conference will be held in Boulder, Colorado, August 13, 14, and 15. It will be held immediately prior to the WESCON meeting in Los Angeles which begins August 19. The Conference will include the dedication of the new Electronic Calibration Center of the National Bureau of Standards. Inspection of the facilities of this new operation by the Bureau should be of considerable interest to the Conference participants.

The Program

Three days of technical sessions for both invited and contributed papers are being planned. In addition, inspection trips will be made through the Boulder Laboratories and nearby field sites. Several speakers of national prominence are being invited to address the Conference and take part in the dedication ceremonies. A banquet and other social events are planned.

The technical program is being organized to parallel the work of the National Bureau of Standards in the development, maintenance, and dissemination of basic standards for electricity, radio, and electronics. Papers to be presented will offer a broad and comprehensive view of standards and measurement techniques and describe the most recent work in this field. Standards and measurements over the entire frequency range from direct current through microwaves will be discussed in six technical sessions.

Technical Sessions

I. The Relationship of Standards to Physical Constants.

a. Methods of using physical constants to express primary standards.

b. The determination of important physical constants by exploiting existing standards.

II. Frequency and Time Interval Standards.

III. Direct-Current and Low-Frequency Standards.

The basic d-c standards; transfer to a-c standards; measurement of current, voltage, power, impedance, attenuation.

IV. Radio-Frequency Standards.

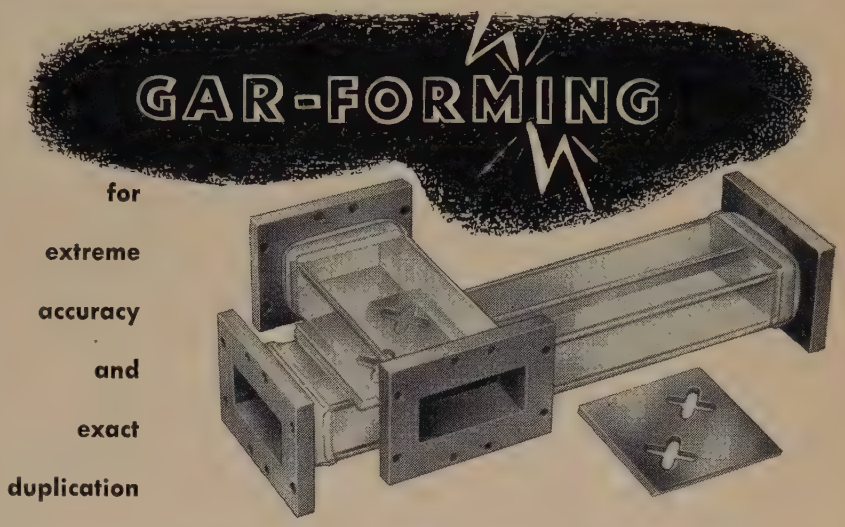
Measurement of voltage, current, power, impedance, attenuation, phase shift, field strength.

V. Microwave Standards.

Measurement of power, impedance, attenuation, noise.

VI. The Organization and Operation of Standards Laboratories.

Radio Building, Boulder Laboratories
Site of Boulder Conference



complex internal shapes made "INSIDE OUT"

This unique electroforming process produces precision, internally-shaped parts, such as this microwave coupler, with internal accuracies and configurations unobtainable or economically prohibitive with any other method.
The intricate interior is formed from the inside out, and may include machined parts that are grown in place during electroforming to produce an integral assembly of unusual accuracy, rigidity, and lightness.
Machined flanges are also grown in exact position to eliminate heat distortion associated with fabrication methods.
Offering new concepts in the design of intricate precision parts, Gar-forming provides highest accuracy in any quantities at surprisingly low costs.

Send today for full information GAR **PRECISION PARTS, INC.**
192 Henry Street, Stamford, Conn.

CIRCLE READER SERVICE CARD 14

BUSINESS

Microwave Engineers

Engineers wanted with two to eight years experience in designing microwave components and instruments.

We are a progressive, expanding firm, among the top five microwave instrument manufacturers, offering full employee benefits, and 100% tuition refund plan for advanced study. Modern, air-conditioned buildings. Pleasant residential area.

Salary: Up to $11,500

Call Mr. Stuart Casper . . . PIoneer 6-4650
THE NARDA MICROWAVE CORPORATION
118-160 HERRICKS ROAD MINEOLA, LONG ISLAND, N.Y.

CIRCLE READER SERVICE CARD 15

D. S. KENNEDY and COMPANY

Cohasset, Massachusetts

Mr. D. S. Kennedy — President, D. S. Kennedy and Co., Cohasset, Mass.

SOMETIMES ACHIEVEMENT in a business venture may be summed up in the words "comprehensive specialization," and this is certainly true of D. S. Kennedy & Co., Cohasset, Mass. The company provides service in the microwave propagation field all the way from research to mass production of antenna equipment.

In fact, the Kennedy story is also pretty much the story of the post-war development of new types of microwave antennas. Founded in 1945 by Donald S. Kennedy, the organization from the beginning has been almost the only one available devoting its energies entirely to antenna design and manufacture. The leading government and research agencies have come to the company for the solution of microwave antenna problems. As a result, many of the design concepts that have since become standard in antennas originated with the Kennedy engineering staff.

Mr. Kennedy founded the company on the basis of his own broad experience in antenna manufacture as well as in other architectural and structural projects. During WW II he was engaged in the design and production of radar antennas and radomes in close cooperation with Radiation Laboratory of MIT. The first company activities were car-

Early Scatter Antenna — 60 ft. diameter

ried out in an old grain mill in Cohasset, Massachusetts. Year by year the demand for Kennedy antenna products increased. Almost every year a new wing was added until all of the original land was used up. This location has become affectionately known as the "topsy plant" from the way it grew and grew.

During the early years of expansion Mr. Kennedy carried the load of both management and engineering. He still retains the function of Chief Engineer, but in 1950 he was joined by Robert J. Grenzeback who became vice president in charge of engineering. Mr. Grenzeback brought to the company a wide experience in the mechanical design of many different kinds of electronic apparatus, particularly in the field of radar antennas with Radiation Laboratory during WW II. Since 1950 he has shared the responsibility for design and production of antenna systems.

The early years of the company were generally concerned with the design and manufacture of radar antennas, especially those using aluminum and plastic materials. This was natural because at that time radar was the principal application of microwave frequencies. But about 1950 a number of new ideas began to appear. For example, by that date scientists had pretty well established that a phenomenon, called tropospheric scatter propagation, had possibilities as a new communication technique. Since the theoretical work had been largely worked out, it remained mainly to try out the idea in real situations. Therefore, a program was instituted by Lincoln Laboratory under the auspices of Rome Air Development Center to construct prototype equipments for testing the new system under field conditions. One of the secrets of scatter propagation is to get a large amount of power into the air; this takes a high power transmitter and a large antenna. By 1953 D. S. Kennedy & Co. supplied a group of 28-foot antennas for the field tests. (Kennedy's previous experience in the fabrication of antennas with aluminum tubing made them well qualified to institute the development of large paraboloids for scatter work.)

The tests carried out by Lincoln Laboratory were successful. Moreover, tropo scatter promised (since then the idea has been confirmed) to be an ideal communication system for the arctic and other far corners of the world. The Air Force, which is charged with the responsibility of maintaining communications in these militarily important regions, moved to establish many of these scatter link sites. To meet these needs Kennedy designed and manufactured several styles and sizes of large antennas, in both aluminum and steel. The company's most popular sizes of paraboloidal reflectors for scatter application are 28, 60 and 120 feet in diameter.

Another new interest involving microwaves that took

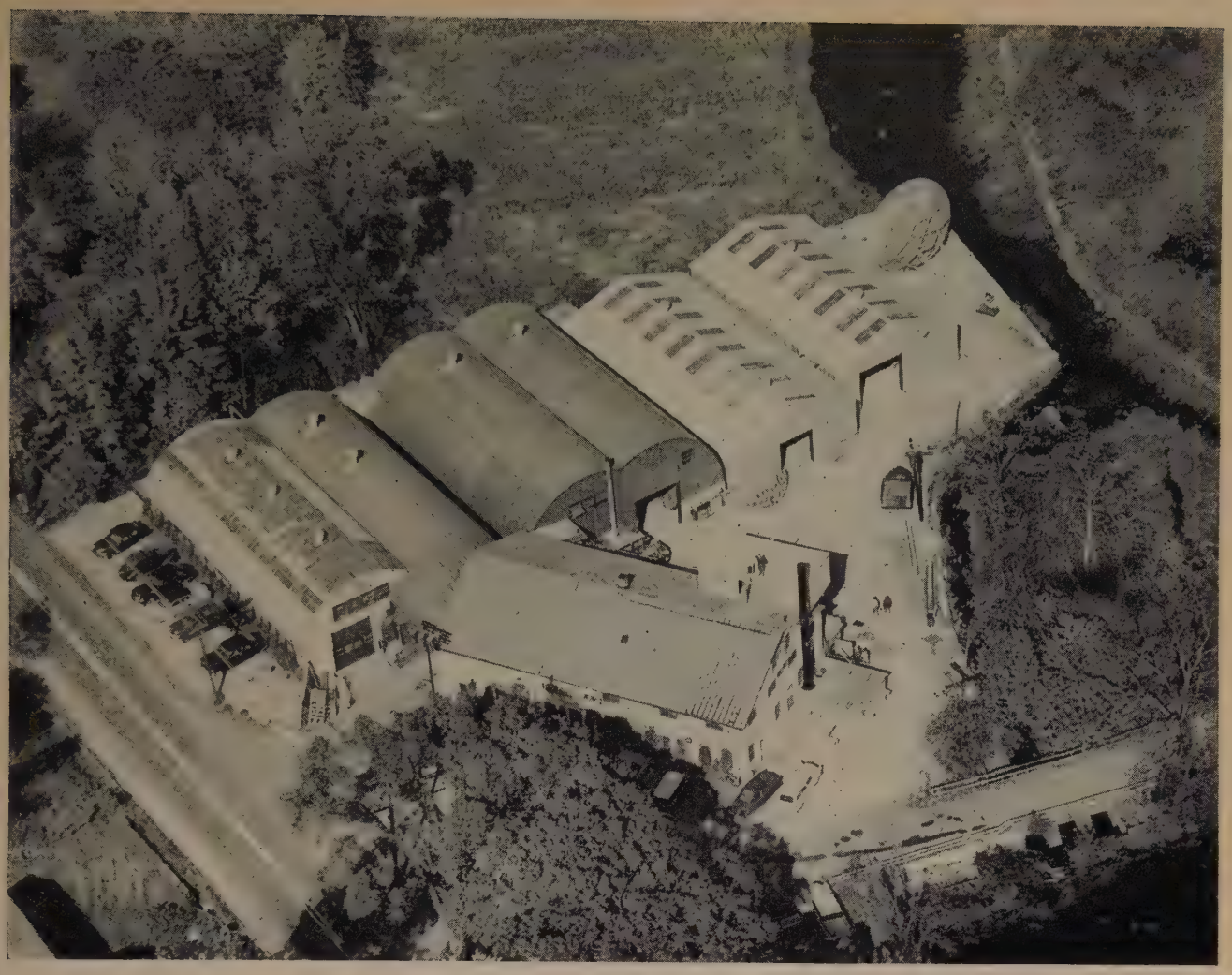
Robert J. Grenzeback, Vice President in charge of Engineering (Left)

root in the '50s is radio astronomy. While this new science had originated in the U.S. with the discovery of cosmic static by Karl Jansky in 1932, and for many years the sole investigator in the world was the American, Grote Reber with his home-made telescope, by 1950 most of the investigation in the field was being carried on by other countries. A special note of recognition is due Harvard University and its observatory staff, including Dr. Harold I. Ewen, Dr. Bart J. Bok and Dr. E. M. Purcell, for bringing radio astronomy back to this country. Early in 1953 the Agassiz Observatory of Harvard took delivery on a 25-foot Kennedy dish, which became the first antenna in this country's reawakened age of radio astronomy. Some say that the Kennedy development of the large aluminum paraboloid had a great deal to do with the practical development of radio astronomy in this hemisphere. Here was a reflector with an aperture large enough to pick up cosmic radio energy, strong enough to withstand the rigors of weather, yet light enough to mount equatorially, as favored by astronomers. In 1955 D. S. Kennedy & Co. designed and built not only the antenna but also the mount and drive system for three 28-foot radio telescopes, two for the University of Alaska and one for Harvard University. The real day of triumph came on April 28, 1956, when Harvard dedicated the Kennedy 60-foot radio telescope. Since then the dish size has been expanded to 84 feet, and Kennedy has built and installed, or has in process, about a dozen of these large instruments.

The same large reflector, supplied with an altazimuth mount, has proved to be very satisfactory for many kinds of trackers. For example, one of the Kennedy radar trackers is operated by Lincoln Laboratory at Westford, Massachusetts, and several Kennedy 60-foot telemetry tracking antennas are installed on the Cape Canaveral missile test range.

Coming back again to radar antennas, Kennedy's specialization in antenna systems has given them the opportunity to design and supply the propagation components for long distance radar sets now being developed and installed. At Bath, Maine, for example, a 120-foot rotating Kennedy antenna functions as a part of the distant early warning system. Other Kennedy antennas of larger size, but too highly classified to discuss, are being manufactured by the company for the ballistic missile early warning system.

To accommodate these greatly expanded operations a modern building of 90,000 square feet was built at Whitney Hill, Cohasset, in 1954. A section of the Hingham Shipyard buildings was also rented for certain heavy construction work. An addition to the Whitney Hill plant is presently planned. In line with the company policy to provide comprehensive service in antenna systems, a West



Original Plant, South Main Street, Cohasset

Coast facility for research and development, Satellite-Kennedy Inc. of California, has recently been established at Palo Alto, and a modern research and development laboratory is to be built at Monterey.

One important phase of the company's activities in complete antenna systems is the waveguide component line, particularly the larger sizes from WR430 to WR2100. Chief of the waveguide and electronics section is Howard J. Rowland, who has an impressive record in antenna design going back to the early days of radar with Radiation Laboratory. He has contributed many notable designs to new horns, transitions, duplexers, high power r-f switches, etc.

Mr. Kennedy's original plan was to supply antenna products in both metal and in fiberglas-reinforced plastic. The plastics department has turned out a steady flow of such products as radomes and plastic-surface reflectors. One important activity of the plastics department has been the production of fiberglas spars used in antenna feed supports. These dielectric members create a minimum of aperture blocking in front of the antenna. Dr. Robert G. Cheatham, a plastics engineer of many years experience is the director of this department.

While comprehensive specialization is one criterion of business success, its opposite, diversification is another. Fiberglas-reinforced plastic products represent one of the areas in which the company plans diversification. A line of marine plastics, such as fiberglas dinghies, is now underway, and assorted contract work is being carried on.

Donald S. Kennedy, president of the firm, said that the Company's sales will exceed $6,800,000 for the fiscal year ended March 31, 1958, a 60 percent increase over fiscal 1957.

Moreover, Mr. Kennedy said that the backlog of orders received this year totals approximately $11,000,000, as compared with more than $6,000,000 a year ago. The company recently completed its initial offering of 100,000 shares of common stock, at a price in the neighborhood of $14 a share. The offering was designed to finance an expansion program, particularly in the fields of development and research.

A forecast was made of a 100 percent increase in the company's sales within five years.

Sales are the life blood, of course, of any business. These activities are handled by Charles W. Creaser, Jr., sales vice president. Mr. Creaser came with the company in 1954, bringing an extensive background of both sales management and engineering.

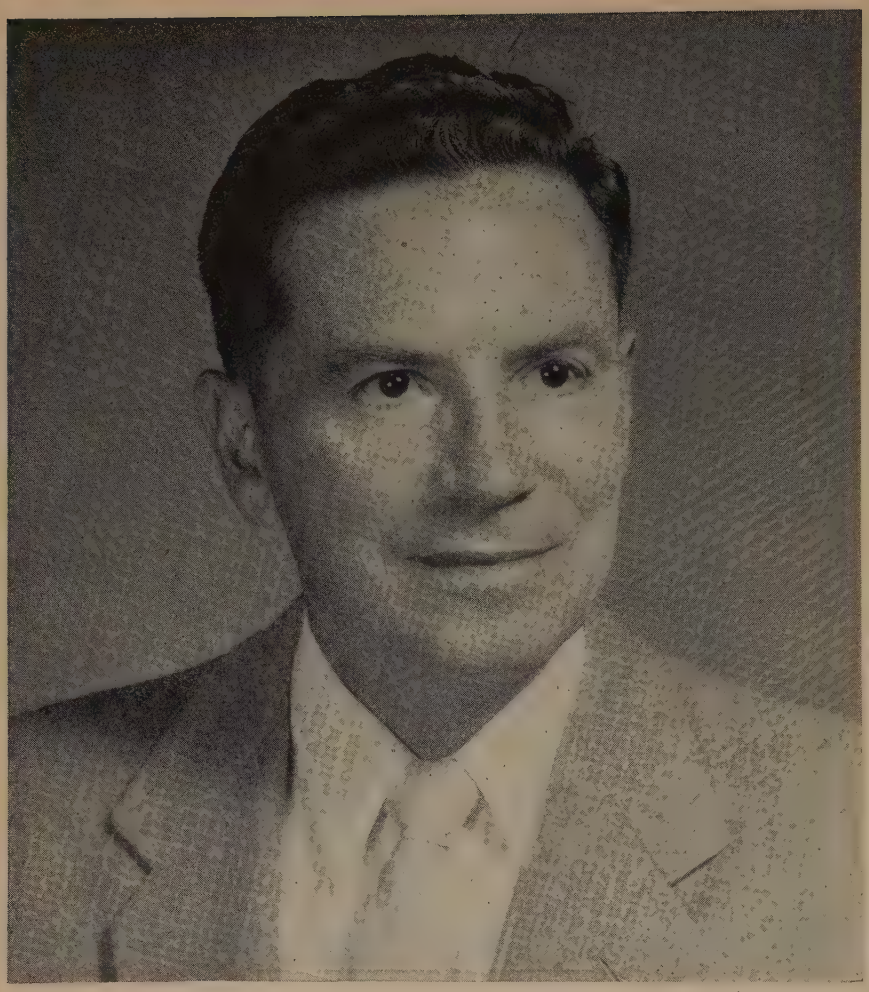
An accurate profile would require an account of the skills and energies of each of the more than 500 persons who now make up the organization, but this is of course impossible here.

BIOGRAPHY

Phillip H. Smith

Bell Laboratories

originator of the Smith Chart



Phillip H. Smith — Bell Laboratories

PUBLICATION IN THIS first issue of the MICROWAVE JOURNAL of the Smith Chart, symbolic of microwave developments because of its universal use in this field, makes it of interest to learn something about the originator of the chart — **Phillip H. Smith.**

Phil Smith was born in the Revolutionary War town of Lexington, Massachusetts on April 29, 1905 within a comparatively short distance of the present MIT Lincoln Laboratory. He stems from Scotch and English ancestry and is a descendant of Ely Whitney, the inventor of the cotton gin. He spent his childhood in Lexington, Massachusetts and after graduation from Tufts College (now Tufts University) in 1928 with the degree of BS in EE, joined Bell Telephone Laboratories. Smith is the author of 14 published articles on transmission lines, antennas, and charts, and has 17 U.S. patents to his credit.

In college Smith was an active "ham" who owned and operated amateur radio station I ANB (the W's were not used in those days). An alternate hobby was playing the cornet in the Tufts College band. To commute between Lexington and Tufts College he drove an old converted model "T" Ford and later a 4-cylinder Harley Davidson motorcycle on which he managed to take more spills than he cares to remember.

At Bell Laboratories, Smith's first assignment was in the Radio Research Department at the Deal Radio Laboratory on the New Jersey coast where he worked under J. C. Schelleng and E. J. Sterba — two well-known radio pioneers — on directional short wave antennas for the trans-Atlantic and ship-to-shore radio telephone. In 1929 he was assigned to the then new short wave A.T.&T. Co. transmitting station at Lawrenceville, New Jersey where he struggled with antenna problems and adjustments of the mile-long line of some 20-odd directional antennas for the trans-Atlantic and South American radio telephone circuits.

During his assignment at Lawrenceville, Smith became interested in graphical aids and nomography as labor saving devices, and about this time he devised the familiar rectangular form of transmission line impedance chart to assist in the rapid evaluation of transmission line formulae with which he was dealing.

In 1934 he was transferred to the Whippany, New Jersey radio laboratory to work on the development of radio broadcast transmitting antennas for Western Electric radio broadcasting equipment. He designed standardized Western Electric Branching and Phasing Units for directional antennas and numerous special phasing and coupling equipments for the directive antennas of radio broadcast stations WOR, WJSV, WRVA, KRLD, and others. Smith was subsequently engaged for a year in broadcast field engineering work. Later, while developing 500 KW coaxial line components for radio station WHAS, Louisville, Kentucky, (it was expected at the time that broadcasters would be licensed for this higher power) Smith obtained a basic patent on the optimum conductor diameter ratio $\sqrt{\varepsilon}$ for a coaxial transmission line. This is the coaxial line ratio

which results in maximum power handling capability for minimum diameter of the outer conductor. Smith says this was one of the simplest patents ever granted — the only claim being the single number, i.e., 1.65.

In 1939-1940, just before America's entry into the war, Smith was sent with a small group of engineers to Ft. Hancock to work with the Signal Corps Laboratories on one of World War II's most important "secret weapons" — radar. He spent one year on Sandy Hook designing antennas and related components for production of the SCR-268 radar. Later he worked on early microwave radar antenna developments for submarine use under W. H. Doherty at Whippany, N.J.

Smith obtained an important basic patent on the adjustable matching stub tuner. After World War II Smith worked on the design of f.m. broadcasting antennas for Western Electric broadcasting equipment. He invented and designed the "Cloverleaf" antenna which Western Electric featured at the time.

In 1954 he supervised a group of electrical engineers concerned with antenna and propagation problems for the DEW line project and SAGE system. At present, he is concerned with antenna and propagation problems for classified military projects.

Smith has been continuously active in IRE committee work since 1947. He has served as a member of the IRE Antennas and Waveguides Committee from 1947 to date and was Chairman of this Committee in 1954-1955. He was Secretary-Treasurer of the IRE Professional Group on Antennas and Propagation in 1954. He received the IRE Fellowship award in 1952 "for his contributions to the development of antennas and graphical analysis of transmission line characteristics."

Smith is best known for his circular transmission line chart which he first published in Electronics Magazine in January 1939 and which has subsequently gained worldwide acceptance.

He has two sons and a daughter by a former marriage. Both sons have served in the Air Force. One spent a year in an isolated part of Alaska while the other was simultaneously in "deep freeze" in Goose Bay, Labrador. His older son, Donald, is presently a sophomore at Stevens Institute of Technology while his younger son, Steven, is employed by the General Electric Company as a member of a radar maintenance team.

Smith's mother and dad, 79 and 78 respectively, are still active and live in the 160-year-old Smith family homestead in Lexington, Massachusetts.

In 1950 Smith took up private flying as a hobby and while on a business trip to White Sands Proving Ground he chanced to visit the Spanish Stirrup—a dude and working ranch in Deming, New Mexico. There he purchased a second-hand light plane from Harley May — the rodeo champion. Smith loves to fly and does so whenever he can for both business and pleasure. He has accumulated about 1200 hours in his own airplane and has made one trip to Mexico City, two trips to California and three to Cuba — the latter being a flying honeymoon trip with his attractive new bride, the former Anita Macpherson of Maplewood, New Jersey, whom he married in March of this year. The Smiths presently live in a garden apartment in Summit, New Jersey.

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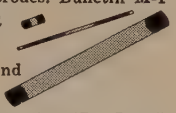

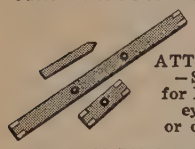

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All-Dielectric Positioning Towers

The new Series 401 "Model Range Towers" for supporting and positioning antennas, reflectors and scale model airframes is announced by Scientific-Atlanta, Incorporated, 2162 Piedmont Road, N.E., Atlanta, Georgia.

The Series 401 Towers, constructed entirely of low dielectric constant materials above the base unit, allows reflectivity or radiation pattern measurements to be made under simulated free space conditions.

Other features include variable speed drive and dual synchro position information for both axes, optional height of 8 and 16 feet by use of an 8 foot extension section and a load capacity of 200 pounds.

CIRCLE READER SERVICE CARD 108

Sylvania Announces Microwave Crystal Diode Mixer Package

WOBURN, MASS.—A series of three premium microwave crystal diodes which permit nearly 20 per cent improvement in radar range with no increase in transmitter power, space or weight, have been announced by Sylvania Electric Products Inc.

The new crystals, designated Types 1N53B, 1N78B, and 1N26A, show marked improvement in over-all noise figure and greater uniformity of RF impedance.

Type 1N53B exhibits an over-all noise figure of 10.3 db, about 3 db better than the 1N53A. In addition, the burnout rating has been increased to 0.3 ergs, from the 0.1 erg rating of the 1N53.

Type 1N78B has an over-all noise figure of 8.8 db, an improvement of greater than 3 db over the 1N78 and 1 db greater than the 1N78A.

Type 1N26A boasts a 1.8 db improvement in over-all noise figure resulting in a new level of 11.3 db. The burnout rating for the newer diode is 0.3 erg, three times that of the earlier version.

Complete technical information on the new crystal diode mixers may be obtained from Sylvania Electric Products Inc., 1100 Main Street, Buffalo, New York.

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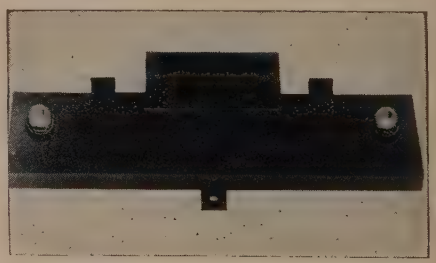


A SPECIAL S-BAND FERRITE ISOLATOR WITH COAXIAL TYPE "N" CONNECTORS

Airtron, Inc., Linden, N.J., announces the availability of a special resonant absorption ferrite isolator for operation in the S-band region, with

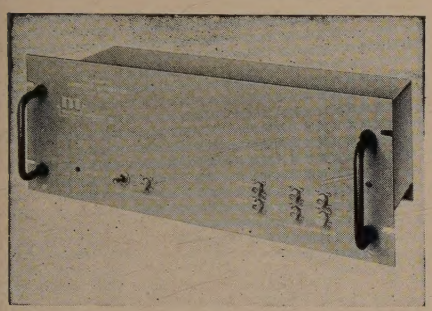
female type "N" connectors to meet particular coaxial systems requirements. This S-band design is typical of some of the special form factors and electrical designs that are possible today by using ferrite materials.

Operating over a frequency range of 2670 to 2930 mcs, the unit is especially beneficial in applications involving power amplifier type of transmitters because of the high degree of unidirectional isolation of the signal source from reflected RF energy.

The electrical characteristics are as follows:

Frequency Range:
2670 to 2930 mc/s
Isolation:
20 db minimum
Insertion Loss:
0.8 db maximum
Input VSWR:
1.20 maximum
Power Handling Capacity:
10 watts average with a 2:1 load VSWR

CIRCLE READER SERVICE CARD 110



Kilomegacycle Reference Generator
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The new Manson Model RD-170 generates both sinusoidal frequencies of 100 mc and 1000 mc and harmonic signals covering a major portion of the microwave spectrum. Output frequency stability is governed solely by the stability of a 1 mc signal which it uses for a reference.

The unit is intended for use as an ultra-precise but low cost source for reference, monitoring or calibrating purposes. Employing crystal synthesizer design techniques, the instrument essentially consists of a free running 100 mc oscillator, which is phase-locked to the 1 mc reference, and multiplier stages which raise the frequency to 1000 mc. A pencil tube in a coaxial cavity forms the final output stage. Power delivered is 100 milliwatts across 50 ohms.

CIRCLE READER SERVICE CARD 111

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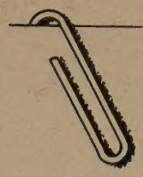

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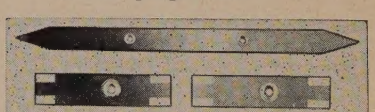

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Our Microwave Industry

Notes of the Industry

By DANA W. ATCHLEY, JR.
PRESIDENT, MICROWAVE ASSOCIATES INC.
BURLINGTON, MASSACHUSETTS

ALTHOUGH THE TECHNICAL aspects of the microwave field are well documented, little is published concerning the makeup of the industry which it supports. The very origin of this new Microwave Journal implies that our industry is large enough to make its publication economical. It is the purpose of this brief editorial to speculate on the present and future dimensions of the microwave industry.

What is the Microwave Industry?

Although the experimental use of microwaves can be traced back to Hertz in 1888, the start of the microwave industry did not occur until the beginning of World War II. With the possible exception of the atomic energy and ICBM fields, it is difficult to find an industry provided with comparable talent and funds so early in its career.

The reader is referred to an excellent review article entitled "Microwaves" authored by Prof. E. L. Ginzton and published in Volume 127 of "Science" 18 April 1958. From this article, it can be seen that microwaves are currently used "in nearly every branch of the military service and are used for radar, communication, and navigation, and for the launching, guidance, and fusing of missiles." While this military use dominates all others, other applications include microwave spectroscopy, "atomic clocks," radio-astronomy, medical and industrial heating, X-ray generation by microwave assisted particle acceleration; and, of course, commercial telecommunication and radar.

Our industry provides much of the engineering and all of the components and systems necessary to supply the above applications. The engineering and production techniques involved are vast and touch almost every field of chemistry and physics.

How Large Is Our Industry?

"Fortune" in its April 1957 issue states that the government bought $3 billion worth of electronic equipment in 1956. Estimates of the portion of this volume uniquely attributable to the microwave industry range from $175 to $300 million. Extending this figure at the rate of $12 thousand per employee, one derives the total employment in the microwave industry at close to 17,500, a respectable segment of our electronic population. The above estimates pertain only to the portion of industrial effort concerned specifically with microwave frequencies. It is difficult to define the exact point where our industry starts and ends. However, it would include the manufacture of microwave antennae, waveguides, duplexers, mixers, microwave tub and solid state devices, but would definitely exclude indicators, power supplies, pedestals, associated computers, etc.

The same issue of "Fortune" lists 108 manufacturers who produce all but $300 million of the *total* electronic industry's $6.2 billion annual output. It is interesting to note that some portion of the sales of 48 of the 108 companies listed must be included with our microwave industry. Of the 19 companies listed who sell over $100 million annually only 3 are not active in our field.

The June 1957 issue of "Electronics Buyers Guide" lists 205 different companies who offer products in the microwave field. This listing includes many who must be considered as fringe companies in our area; on the other hand, Western Electric and Hughes Aircraft are not listed and they certainly are among our industry's leaders.

Other interesting statistics include the fact that approximately 7% of the membership of the Institute of Radio Engineers are also members of their Professional Group on Microwave Theory and Techniques whereas 21% of the product advertising in the May 1958 issue of the Proceedings was devoted to microwave devices, a tribute to the creativity of the microwave engineer.

How About the Commercial End of the Industry?

Regrettably, the commercial uses of microwave, while certainly important to us all, represent only a small portion of our industry's effort. The writer estimates the total annual commercial volume at from $15 to $20 million — a figure which is less than the probable error in my estimate of military microwave sales.

What is Our Industry's Growth Potential?

It would be nice to correlate our growth possibilities with such new technology as masers, parametric amplifiers, new tube types, etc. and their many new applications. However, the writer is forced to conclude that future growth or contraction, at least over the next ten-year period, will be more a function of our defense policies. In this respect, from what has been published concerning the recommendations of the Gaither, Rockefeller, and ORO reports, it is apparent that, if a substantial portion of their recommendations are adopted by the Department of Defense, such action must involve expansion of our industry.

Over the long range, growth in many areas appears promising, namely:

1. As the requirement develops for exchange of information at higher speeds, whether it be of approaching missiles, air traffic control or stock market quotations, it is inevitable that microwave wavelengths will see increased utilization.
2. The development of better and cheaper microwave components will accelerate the rush to the microwave regions. It is anticipated that much of these new advances will involve solid state and gaseous physics.
3. The next decade will see increasing use of microwaves for instrumentation in connection with measurement through hot, ionized gases such as is encountered in magnetohydrodynamics, thermal fusion and ICBM reentry.

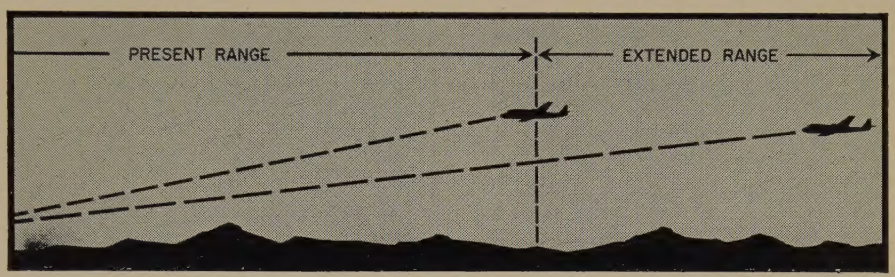
The writer is of the opinion that the microwave industry will continue the prosperous growth that it has demonstrated during the past 18 years.

MICROWAVE AND SPECIAL TUBE NEWS from SYLVANIA

New Mixer Diodes can extend Radar Range by 18%

Premium 1N78B, 1N26A and 1N53B improve new and existing radar with unmatched ease and economy

Three new microwave diodes covering applications from 13,000 mc to 35,000 mc are now available from Sylvania. The new mixers, types 1N78B, 1N26A and 1N53B, have improved overall noise figures, more uniform RF impedance, and two of the types have greater resistance to burnout. They can extend radar coverage by as much as 18 percent*, provide more uniform performance from system to system, and increase operational reliability. An equivalent upgrading of equipment by any other means would demand a twofold increase in power.



How radar range increases with Sylvania's new premium crystal diodes

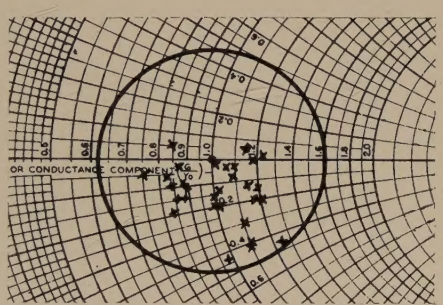
The new crystals are exact retrofits of preceding types and are comparable in price. Each type is available in matched pairs to Sylvania's specification, which has recently been accepted as the industry standard by JETEC 14.7.

*2.8 db improvement in overall noise figure of 1N53B yields 18% increase in range.

Type 1N78B—Used in applications from 13,000 mc to 16,500 mc, the diode has an overall noise figure of 8.8 db, an improvement of 3 db over the 1N78 and 1 db over the 1N78A. It is being used extensively in doppler navigation equipment and in fire-control radar.

Type 1N26A—Designed for use as a mixer in superheterodyne radar receivers in the 24,000 mc region, the type is primarily used in airport traffic control equipment and in air-to-air missiles. Its 11.3 overall noise figure is a 1.8 db improvement over the 1N26. Its burnout resistance rating has been increased threefold to 0.3 erg.

Type 1N53B—This miniature coaxial type point contact silicon diode is designed for use as a mixer in the 35,000 mc region. Its major application is in Terrain Avoidance and Mapping Radar. The burnout resistance rating of the 1N53B is double that of the 1N53 and its overall noise figure has been reduced from 13.14 to 10.3. It is tested for a band width of 12 percent to assure good performance in any application in its frequency range. The new diode can also be used as a harmonic generator for very short wave-lengths.


VSWR measurement of a random selection of 1N78B's indicates the positive control over RF impedance of new Sylvania crystal mixers. The circle shows a VSWR of 1.6

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Electrical Characteristics & Ratings

	IN78B	IN26A	IN53B
Conversion Loss (db) max.	6.5	7.5	6.5
Output Noise Ratio max.	1.3	2.0	2.0
IF Impedance (Ohms)	365-565	300-600	400-800
RF Impedance (VSWR) max.	1.6	1.6	1.6
Burnout (erg)	0.3	0.3	32.8-37.0
Frequency (kmc)	16	24	0.3

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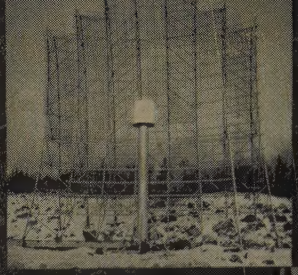

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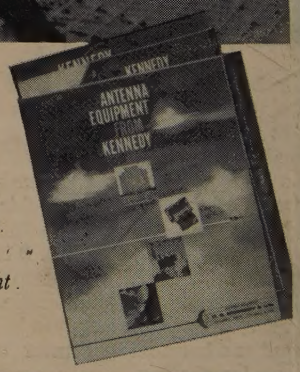

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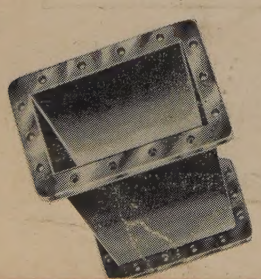

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